AD-A278 426

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE November 1988

3. REPORT TYPE AND DATES COVERED Technical June-July 1988

4. TITLE AND SUBTITLE
Advanced Conventional Armaments Technology Panel Report Supplement: Cannon and Rocket Parametric Tradeoff Analyses

5. FUNDING NUMBERS
C

6. AUTHOR(S)
Steven M. Buc

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
System Planning Corporation
1500 Wilson Blvd
Arlington, Virginia 22209

8. PERFORMING ORGANIZATION REPORT NUMBER
SPC 88-1465-11

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Advanced Research Projects Agency
3701 North Fairfax Drive
Arlington, Virginia 22203-1714

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Contract No. F29601-86-C-0026

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

An Advanced Conventional Armaments Panel was formed as part of a DARPA-sponsored assessment of the utility of electric guns in the fire support, anti-armor, and air defense mission areas. This panel was assembled and tasked to focus on identifying the near and intermediate-term capabilities that advanced conventional (non-electric gun) technologies could offer in each of the above mission areas.

This supplemental report contains first order conventional launch system parametric tradeoffs in the form of carpet plots, which present the performance capabilities of cannon and rocket systems. The utility of these tradeoff relationships is that they permit both the non-electric and electric gun and projectile designers to consider the most cost effective approach to satisfying their mission area requirements. This report also contains a survey of existing system performance parameters, and two projectile point designs.

14. SUBJECT TERMS
long range artillery cannons and rockets, anti-tank guns, interior ballistics, trajectories, payload

15. NUMBER OF PAGES 70

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

13P8

SPC 88-1465-11

ADVANCED CONVENTIONAL ARMAMENTS TECHNOLOGY PANEL REPORT SUPPLEMENT

CANNON AND ROCKET PARAMETRIC TRADEOFF ANALYSES

Accesion For	
NTIS CRA&I	X
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution /	
Availability Codes	
Dist	Avail and / or Special
A-1	

NOVEMBER 1988

Prepared for:

David Hardison, Director
Electrical Energy Gun System Study

and

Dr. Clarence W. Kitchens, Jr., Chairman
Advanced Conventional Armaments Panel

Prepared by:

Steven M. Buc

System Planning Corporation
1500 Wilson Blvd
Arlington, Virginia 22209

CONTENTS

1. BACKGROUND

An Advanced Conventional Armaments Panel was formed as part of a DARPA-sponsored assessment of the utility of electric guns in the fire support, anti-armor, and air defense mission areas. The Advanced Conventional Armament Panel was assembled and tasked to focus on identifying the near and intermediate-term capabilities that advanced conventional (non-electric gun) technologies could offer in each of the above mission areas. For the purposes of this study, advanced conventional armament alternatives are defined to include both powder gun and propellant based missile/rocket options.

This supplemental report contains first order conventional launch system parametric tradeoffs in the form of carpet plots, which present the velocity, range, and payload capabilities of cannon and rocket systems. The utility of these tradeoff relationships is that they permit both the non-electric and electric gun and projectile designers to consider the most cost effective approach to satisfying their mission area requirements. This report also presents a survey of existing conventional cannon and missile systems in terms of their relevant performance parameters. Finally, two projectile point designs are developed to satisfy postulated special operations requirements, for which there currently exist no conventional or electric gun equivalent.

2. PROPOSED ELECTRO-MAGNETIC GUN SYSTEM PARAMETERS

Table 2.1 shows the proposed electro-magnetic gun system parameters by mission area, on which the overall electric gun study was to focus.

Table 2.1
EM Gun System Parameters by Mission Area [1]

Mission/Role	Platform	Range Km	Proj Wt Kg	Vel Km/sec	Energy MJ
Fire Support					
Close Support	Vehicle	50	50	1.1	30
	Ship	50	50	1.1	30
Deep Support	Vehicle	100	100	1.2	72
	Ship	100	100	1.2	72
Very Deep	Fixed Site	500	110	2.3	290
Counter Armor					
Anti-Tank	Tank Cannon	3.5	11.7	1.7	17
		3.5	5.4	2.5	17
		3.5	3.7	3.0	17
	Tnk Destroyer	6	17	1.7	25
		6	8	2.5	25
		6	5.6	3.0	25
Counter Air					
Fixed Site	Area Defense	100	5	3	22.5
	Over the Horizon	450	30	3.6	194
Ship					
	Point Def.	3	0.5	3.0	2.25
	Local Def.	10	9	2	18
	Area Def.	100	18	2.5	56
	Area Def.	5.5	6	3.6	39
	Over the Horizon	450	30	3.6	194
Vehicle					
	Point Def.	3	0.5	2.0	1.0
	Local Def.	10	9	2	18
	Area Def.	100	18	2.5	56
	Area Def.	11	6	3.6	39
Special Ops Fixed Wing A/C					
	Anti-Material	7	0.4	2.5	1.25
	Anti-Fortif.	5	2.5	2.2	6.0

---

1 These proposed EM gun system parameters are taken from the final report, dated November 1988, of the Threat, Projectiles, Fire Control and Terminal Effects Panel of the Electrical Energy Gun System Study.

Table 2.2 shows some current system characteristics with respect to the same performance parameters.

Table 2.2
Some Current System Characteristics[2]

System	Range Km	Proj Wt Kg	Vel Km/sec	Energy MJ
Missiles		(Warhead	Burnout	Burnout)
STINGER SAM	5.5	0.9	0.7	0.22
SPARROW AAM	44	41	0.87	15.5
SIDEWINDER AAM	3.7	11.4	0.87	4.3
PHOENIX AAM	135	60	1.5	68
PATRIOT SAM	68	125	1.0	63
MAVERICK (65E)	25.8	136	0.35	8.3
MAVERICK (65D)	25.8	59	0.35	3.6
IHAWK SAM	46.1	81	0.9	31
HELLFIRE	7.4	9.1	.35	.55
HARPOON ASM	110	231	.28	9
HARM	18.4	66	1.2	49
Cannon Anti-Tank				
105mm	1.8	5.8	1.5	6.6
120mm	3.5	7.0	1.7	10
Cannon Artillery Fire Support				
105mm	11.3	2.7	.47	.30
155mm	18.1	43	.68	10
155mm HERA	30.1	44	.83	14.9
8 inch	16.8	93	.60	16.7
8 inch XM201	21.3	93	.72	23.8
Naval Guns				
16 inch	36.6	300	.82	102

2 Multiple sources

Table 2.3 (a) expands the proposed EM projectile mission role parameters to show required firing rates and duty cycles. Table 2.3 (b) breaks the desired projectile weight and muzzle energy into the lethal and parasitic components, such as the penetrator and sabot.

For comparison purposes, the tables 2.4 through 2.9 present similar information, as available, for some conventional cannon and missile systems for these same mission areas.[3] This survey is not intended to be exhaustive, but rather representative of some common and exceptional conventional systems available now, or shortly to be fielded.

Table 2.10 normalizes some of the system parameters for conventional cannon and missile systems with respect to several important system parameters. Since the overall intent of developing EM guns is to field more efficient as well as effective weapon systems for each mission area, comparing energy versus system weight parameters is very useful when comparing how EM guns will measure up to their conventional counter parts. In these tables, shot energy is based on the projectile weight for cannon systems at muzzle velocity, and for missile systems it is the useful payload weight at burnout velocity. In addition, the system weight is based on the weight of the gun and one round of ammunition in the case of cannon systems. For missile systems, it is the weight of the missile and its packaging. Any self- propelled vehicle or battleship weight is not included in these comparisons.

Some interesting observations can be made from the data in Table 2.10. Firstly, in the One Shot Basis column, some very impressive muzzle and burnout kinetic energies are obtainable with conventional cannon and rocket delivery systems. In particular, the 16 inch naval gun and the ATACMS artillery missile. (For the ATACMS missile, as with all the missile data in these tables, kinetic energy is based on the useful payload mass.) Unfortunately, one 16 inch tube and breech weigh nearly 51 tons, so this is a very heavy system to achieve this level of muzzle energy. The ATACMS missile system is much more energy efficient.

[3] Multiple sources.

The Equal Energy Basis column normalizes the effective system weight to realize equivalent payload energies for each system shown. The system weights change slightly to represent the firing of several rounds of ammunition to make up for the differences in one shot energy. The 16 inch gun and ATACMS missile are excluded from this column since they represent extreme conditions. One observes that the weight efficiency of conventional cannons is very close, as are the missile system comparisons. In addition, missiles are more weight efficient for their useful payload kinetic energy.

The last column, Equal Throw Weight Basis, normalizes the data for useful payload weight, which may represent high explosive or submunition cargo. Again, system weights are increased or decreased to normalize shot throw weights based on number of shots. On the average, missile systems are slightly more efficient at delivering cargo to extended ranges, with ATACMS being the best performer. However, the 155mm artillery systems are very good contenders. As one might expect, the 120mm gun on the M1A1 tank is not very weight efficient from a projectile throw weight point of view, since it is not intended to be an artillery delivery system. This cannon is designed primarily for kinetic energy defeat of threat tanks.

Table 2.3(a)
Proposed EM Gun Mission Areas and Duty Cycles

			MISSION			AMMUNITION		
Role	Platform	Representative Targets	Operational Range (km)	Duty Burst Rate of Fire	Cycle Sustained Fire Mission	Launch Mass (kg)	Muzzle Velocity (km/sec)	Energy per Round (MJ)
			Fire Support			Includes Sabot		
Close Support	Ground Vehicle	Combat Units	50	4 Rounds in 15 sec	2 Rounds per min for 20 min	50.00	1.1	30
Close Support	Ships	Ground Units, Ships	50	4 Rounds in 15 sec	2 Rounds per min for 20 min	50.00	1.1	30
Deep Support	Ground Vehicle	Mov Vehicles, Sta Assy	100	5 Rounds in 120 sec	0.5 Rounds per min for 20 min	100.00	1.2	72
Deep Support	Ships	Ground Units, Ships	100	5 Rounds in 120 sec	0.5 Rounds per min for 20 min	100.00	1.2	72
Very Deep Support	Stationary	Fixed Area Targets	500	5 Rounds in 120 sec	0.5 Rounds per min for 20 min	110.00	2.3	290
			Close Combat - Counter Armor					
Mounted	Tank	Tanks, Mat, Soft	3.5	2 Rounds in 5 sec	6 Rounds per min for 1 min	11.70	1.7	17
					24 Total # of rounds in 12 min	11.70	1.7	17
Close Combat			3.5	2 Rounds in 5 sec	6 Rounds per min for 1 min	5.40	2.5	17
					24 Total # of rounds in 12 min	5.40	2.5	17
			3.5	2 Rounds in 5 sec	6 Rounds per min for 1 min	5.40	2.5	17
					24 Total # of rounds in 12 min	5.40	2.5	17
			3.5	2 Rounds in 5 sec	6 Rounds per min for 1 min	3.70	3.0	17
					24 Total # of rounds in 12 min	3.70	3.0	17
Anti-Tank	Tank Destroyer	Tanks	6	2 Rounds in 5 sec	6 Rounds per min for 1 min	17.00	1.7	25
					24 Total # of rounds in 12 min	17.00	1.7	25
			6	2 Rounds in 5 sec	6 Rounds per min for 1 min	8.00	2.5	25
					24 Total # of rounds in 12 min	8.00	2.5	25
			6	2 Rounds in 5 sec	6 Rounds per min for 1 min	5.60	3.0	25
					24 Total # of rounds in 12 min	5.60	3.0	25
			Counter - Air & Missile					
Self Defense	Ships	Sea Skimmers	3F/2L	100 Rounds in 2 sec	4 Bursts per min for 2 min	0.50 (1)	3.0	2.25
High vel. Pt. Defense	Ground Vehicle	AC, TASM, ARM, TBM	3F/2L	100 Rounds in 2 sec	4 Bursts per min for 2 min	0.50 (1)	2.0	1
		CM		4 Rounds in 4 sec	4 Bursts per min for 2 min	9.00	2.0	18
Local	Ships	AC	10F/4L	10 Rounds in 60 sec	10 Rounds per min for 2 min	9.00	2.0	18
	Ground Vehicles	AC, CM	10F/4L	10 Rounds in 60 sec	10 Rounds per min for 2 min	9.00	2.0	18
Area	Ships	AC, CM	100F/50L	1 Round	6 Rounds per min for 4 min	18.00	2.5	56
	Ground Vehicles		100F/50L	1 Round	6 Rounds per min for 6 min	18.00	2.5	56
	Fixed Site		100F/50L	1 Round	6 Rounds per min for 6 min	18.00	2.5	56
Area	Ships	ASM	5.5	8 Rounds in 30 sec	0.5 Bursts per min for 4 min	6.00	3.6	39
	Ground Vehicle	TBM	11	8 Rounds in 30 sec	0.5 Bursts per min for 4 min	6.00	3.6	39
OTH AD	Ships, Sites	AC	450	1 Round	0.5 Rounds per min for 20 min	30.00	3.6	194
			Special Operations					
Anti-Materiel	Special Ops. AC	Radars, Trucks	7	10 Rounds in 10 sec	2 Bursts per min for 2 min	0.40	2.5	1.25
Anti-Fortification	Special Ops. AC	Bunkers	5	1 Round	10 Rounds per min for 2 min	2.50	2.2	6.05

Table 2.3(b)
Proposed EM Projectile/Sabot Parameters

PROJECTILE / SABOT PARAMETERS — POWER EXITING THE MUZZLE

Sabot Mass (kg)	Flight Mass (kg)	Projectile Length (m)	Projectile Diameter (m)	Sabot Diameter (m)	Peak Acceleration (m/s^2)	Projectile Sabot Efficiency							Burst Muzzle Power (kW)	Sustained Muzzle Power (kW)
Fire Support														
5.00	45.00	0.90	0.155	0.165	1.47 (10)^5	90%							8,067	1,000
5.00	45.00	0.90	0.155	0.165	1.47 (10)^5	90%							8,067	1,000
10.00	90.00	2.00	0.155	0.200	2.0 (10)^5	90%							3,000	600
10.00	90.00	2.00	0.155	0.200	2.0 (10)^5	90%							3,000	600
10.00	100.00	0.78	0.200	0.200	4.0(10)^5	91%							12,083	2,417
Close Combat - Counter Armor														
	5.30		≥ 0.02	0.135	6.0 (10)^5								6,763	1,691
	5.30		≥ 0.02	0.135	6.0 (10)^5									564
	3.20		0.023	0.165	7.0 (10)^5								6,750	1,688
	3.20		0.023	0.165	7.0 (10)^5									563
	[illegible]		0.015	0.135	7.0 (10)^5								6,000	1,700
	2.40		0.015	0.135	7.0 (10)^5									563
	1.70		≥ 0.012	0.135	1.2(10)^6								6,660	1,665
	1.70		≥ 0.012	0.135	1.2(10)^6									555
	8.00		≥ 0.020	0.145	6.0 (10)^5								9,826	2,457
	8.00		≥ 0.020	0.145	6.0 (10)^5									819
	3.70		≥ 0.015	0.145	≤ (10)^6								10,000	2,500
	3.70		≥ 0.015	0.145	≤ (10)^6									833
	2.50		≥ 0.012	0.145	≤ (10)^6								10,080	2,520
	2.50		≥ 0.012	0.145	≤ (10)^6									840
Counter - Air & Missile														
0.05	0.45	0.12	0.040(1)	0.040	7(10)^5	90%							112,500	15,000
0.05	0.45	0.12	0.040(1)	0.040	7(10)^5	90%							50,000	6,667
													18,000	4,800
1.55	7.45	1.00	0.120	0.120	5 (10)^5	83% (4)							3,000	3,000
1.55	7.45	1.00	0.120	0.120	5 (10)^5	83%							3,000	3,000
3.50	14.50	1.00	0.100	0.120	5 (10)^5	81%							7,500	7,500
3.50	14.50	1.00	0.100	0.100	5 (10)^5	81%							7,500	7,500
3.50	14.50	1.00	0.100	0.100	5 (10)^5	81%							7,500	7,500
1.50	4.50	0.90	0.120	0.120	9.8 (10)^5	75%							10,368	2,592
1.50	4.50	0.90	0.120	0.120	9.8 (10)^5	75%							10,368	2,592
2.50	14.50	1.00	0.100	0.100	5(10)^5	85%							1,620	1,620
Special Operations														
0.04	0.38	0.14	0.020	0.02	7(10)^5	90%							1,250	417
0.50	2.00	0.15	0.030	0.03	7(10)^6	90%							1,000	1,000

Table 2.4
Current Air Defense Missile and Gun System Parameters

Parameter \ Air Defense Missiles & Guns	ADATS 152mm	IHAWK 360mm	Sparrow Hawk 200mm	Patriot 410mm	Standard II 393mm	Standard II 343mm	Sea Vulcan M197 20mm	Sea Vulcan GAU/8A 30mm
Muzzle/ Sustained Velocity (m/s)	1250	850	850	1000	1000	1000	1036	1021
Slant Range/Altitude (km)	10/6	40/30	40/30	70/45	115/45	70/45	CIWS	CIWS
Projectile Wt. (kg)/Type	51.4	627.3	228	1000	1442	700	0.101 HEI	0.36 HEI
Average CEP							7 mil	5 mil
Gun/Launcher Weight (kg)							66	1723
Gun Dimensions (m)	2x2	5x2	4x2.5	6x1	8x1	5x1	1.9m length	6.4m length
Basic Load per Tube/Launcher	8	3	9	1	1	1	6000	1190
Weight Basic Load (kg)	411	1882	2600	1000	1442	700	1540	809
Burnout/Sustain/ Muzzle Energy (MJ)	21	93	35	200	291	140	0.0542	0.188
Launch Gs	200	30	50	15	10	10		
Payload Weight (HE) (kg)	12.5	80	40	125	65	65		
Payload Energy (MJ)	10	29	15	63	32.5	32.5		
Propellant Weight (kg)	25	370	130	600	860	420	0.039	0.152
Rate of Fire (rd/min)	2						750/1500	2100/4200
Average Recoil Force (kg)							545	

Table 2.5
Current Anti-Tank Gun System Parameters

Current Antitank Guns / Parameter	120 M256		105 M68					
Muzzle Velocity (m/s)	1750	1650	1501	1508				
Maximum Range (m)	3500		1800					
Projectile Wt. (kg)/Type	7 DU M829	M827	W M735	5.8 DU M774	6.2 DU M883			
Average CEP								
Gun Weight (kg)	1905		1128					
Gun Dimensions (mm)	6168		5550					
Basic Load per Tube	40 M1A1		63 M60A3					
Weight Basic Load (kg)	748	789	1452	1086				
Muzzle Energy (MJ)	10.72			6.6				
Launch Gs	70,000							
Max. Recoil Force (Kn)	600							
Rate of Fire max/norm			10/6					
Flight Proj. Wt. (kg)	4.2							
Flight Energy (MJ)	6.43							
Propellant Weight								
Payload Weight								
Payload Energy								

Table 2.6
Current Rocket Artillery System Parameters

Rocket Artillery / Parameter	MLRS 227mm Phase I	MLRS 236mm Phase II	MLRS 236mm Phase III	ATACMS 610mm				
Burnout Velocity (m/s)	750	800	850	1500				
Maximum Range (km)	32	40	45	190				
Projectile Wt. (kg)	307	257.5	257.5	1850				
Average CEP								
Launcher Weight (kg)	1320	1320	1320	1320				
Launcher Dim. (m)	4x3	4x3	4x3	4x3				
Basic Load / Launcher	12	12	12	2				
Weight Basic Load (kg)	3684	3090	3090	3700				
Burnout Energy (MJ)	65	58	63	1173				
Launch Gs	400	400	400	40				
Rate of Fire (rd/min)	12	12	12	2				
Payload Weight (kg)	154	107	107	240				
Payload Energy (MJ)	43	34	39	270				
Propellant Weight (kg)	77	77	83	925				

Table 2.7
Current Naval Gun System Parameters

Parameter \ Current Naval Guns	16" AP	HC	HC/ Submun	HC/ DSSC	5"/38	5"/54		
Muzzle Velocity (m/s)	739	823	823	1250	793	808		
Maximum Range (m)	36576	38000	38000	90000	16500	23700		
Projectile Wt./Type (lb)	2695	1880	1880	1100	55	70		
Average CEP (m)								
Gun Weight	54.5 t	54.5 t	54.5 t	54.5 t	2 t	2.75 t		
Gun Dimensions (in)	799	799	799	799	190	270		
Basic Load per Ship	1220				40	40		
Weight Basic Load (t)	1250.5				1.7	2.02		
Muzzle Energy (MJ)	334	289	289	390.6	7.86	10		
Launch Gs	3251	4449.8	4449.8	6876.9	14000	11500		
Application	BB-61				Mk28 Mk38	Mk 39 Mk42 Mk45		
Rate of Fire (rds/min)	2	2	2	2	15	20/40		
Recoil								
Charge Weight (lb)	660	660	660	660	15	20		
Explosive Filler Wt.								
Explosive D (kg)	18	70						
Composition B (lb)					9	12		
Submunitions (kg)			150					

Table 2.8
Current U.S. Howitzer System Parameters

Parameter \ Current Howitzers	155 M1A1 M1A2	155 M126 M126A1	155 M185 M185E1	155 M199				
Muzzle Velocity (m/s)	564	561	680	826				
Maximum Range (m)	14600	19300	23714	30100				
Projectile Wt./Type (lb)	95 M107	96 M549A1	96 M549A1	96 M549A1				
Average CEP								
Gun Weight (lbs)	3750	3200	4330	4850				
Gun Dimensions (length)	158 in	177 in	272 in	240 in				
Basic Load per Tube	34	34	34	34				
Weight Basic Load (lbs)	3681	3715	3955	4154				
Muzzle Energy (MJ)	6.85	6.85	10.06	14.85				
Launch Gs	11,320	11,570	10,000	14,700				
Application (systems)	M114 M114A1 M114A2	M109	M109A1 M109A2 M109A3	M198				
Rate of Fire (rpm)	4	4	4	4				
Recoil								
Charge Weight (lbs)	13.28	13.28	20.34	26.19				
Explosive Filler/Wt.								
Composition B (lbs)	15.4	16	16	16				
TNT (lbs)	14.6	15	15	15				

Table 2.9
Current Foreign Howitzer System Parameters

Current Howitzers Foreign / Parameter	155 Belgium PRB	155 South Africa ARMSCOR							
Muzzle Velocity (m/s)	897	897							
Maximum Range (m)	39,000	39,000							
Projectile Wt.(lb)/Type	105 HEBB	104 HEBB							
Average CEP									
Gun Weight (lb)	5325	5325							
Gun Dimensions (in)	315	315							
Basic Load per Tube									
Weight Basic Load									
Muzzle Energy (MJ)	19.16	18.91							
Launch Gs									
Application	45 cal tubes	G5 G6 SPH							
Rate of Fire									
Recoil									
Charge Weight									
Explosive Filler Wt.									
TNT (lb)	18	19.2							

Table 2.10
Normalized Comparisons of Shot Energy, System Weight, and Shot Throw Weight for Conventional Systems

	One Shot Basis		Equal Energy Basis		Equal Throw Weight Basis		
System	Shot Energy(MJ)	System Weight(kg)	Shot Energy(MJ)	System Weight(kg)	Shot Throw Weight(kg)	System Weight(kg)	Shot Energy (MJ)
155 PRB	19.16	2474	289	3312	853	3481	343
155 S. A.	18.91	2474	289	3317	853	3483	342
M199	14.85	2255	289	3278	853	3285	291
M185	10.06	2016	289	3479	853	2997	197
M126	6.85	1501	289	3542	853	2422	134
M1A1	6.85	1750	289	3772	853	2673	136
5"/38	7.86	1846	289	2900	853	2981	[illegible]69
5"/54	10	2535	289	3674	853	3591	269
16"HC	289	50585	289	50585	853	50585	289
16"SC	390.6	50231					
MLRS1	65	1627	289	2685	853	2458	241
MLRS2	58	1578	289	2603	853	2537	274
MLRS3	63	1578	289	2501	853	2579	308
ATACMS	1173	3170			853	3748	1539

3. CONVENTIONAL GUN SYSTEM PARAMETRIC TRADEOFFS

With the objective of characterizing chemical energy guns in terms of variables which allow direct comparison to alternative methods of launch such as rockets and EM/EM-ET, the following parametric relationships are presented. The sum total of these relationships should indicate what is required to launch a given projectile mass at a certain muzzle velocity, and provide a means of bounding the problem with respect to other weapon system aspects and requirements. A short discussion is presented on each parametric relationship, and some have been graphed. This list is not claimed to be complete or entirely feasible, but does serve as a starting point for analysis.

A. Launch velocity versus projectile mass and muzzle energy.

Figure 3.1 (a) and (b)

Muzzle energy (megajoules) *is a term* commonly used to compare EM gun output and requirements. It is useful for reference, therefore, to apply this term to all projectile launch systems. The simple kinetic energy equation relates projectile mass and velocity to muzzle energy: $E = 1/2\ M\ V^2$. The performance of representative current cannon systems can be called out on the chart for comparisons by referring back to the parameter tables shown earlier.

B. Sabot ramp mass versus penetrator mass and penetrator L/D

Figure 3.2

Advanced projectile designs intended to boost the muzzle and terminal velocity of kinetic energy projectiles, as well as long range sub-caliber artillery projectiles rely on a discarding sabot. This sabot adds parasitic weight which decreases the useful kinetic energy or payload weight of the projectile. This chart shows how the mass of the sabot forward and aft ramps grow as the penetrator or flight projectile becomes longer. The assumption here is that the sabot is of the double ramp design as opposed to the saddle-back approach. The double ramp design has greater weight and longitudinal structural efficiency than the saddle-back sabot and is typified by the 120mm M829 design. Calculations supporting this curve are based on well known structural mechanics formulations for tri-axial loading in the aft ramp of the sabot, and uniaxial compressive acceleration loading on the front ramp of the sabot.

C. Sabot total mass versus sabot ramp mass and gun tube diameter Figure 3.3

The weight of the sabot ramps, however, is not the complete story on the weight of the parasitic sabot. The central sabot bulkhead must be provided for to completely seal the gun tube. For a given projectile acceleration and base pressure, the ramp weight will be the same regardless of the diameter of the tube. However, the diameter of the tube will force a weight growth in the sabot bulkhead. This chart shows takes the sabot ramp weight and adds the required bulkhead weight as the gun tube diameter changes.

D. Launch acceleration versus projectile mass and base force (base pressure per tube area)

(not shown)

Launch acceleration is an important parameter for the projectile structural designer. Through $F = M A$, Varying projectile mass and base pressure in the gun tube relates projectile acceleration to the gun system parameters. Using base force makes the graph applicable to any gun tube diameter.

E. Base pressure versus chamber pressure and projectile mass per propellant mass.

(not shown)

Since base pressure is the projectile designer's parameter and chamber pressure is the cannon designer's parameter, some relationship must be defined to combine the two. This relationship is found through the pressure gradient in the gun tube between the propellant which generates pressure in the gun chamber and the base pressure behind the projectile which drives it through the tube. A first order approximation is based on the projectile mass and propellant mass ratio. A ratio is used here in order to make the curves valid for all projectile and propellant masses considered.

Using the relationship:

$$P_b = \frac{P_c \bullet M_p}{M_p + .5M_c} \qquad (1)$$

where P_b = base pressure
P_c = chamber pressure
M_p = projectile mass
M_c = propellant charge mass

$$P_b = \frac{P_c \bullet M_p / M_c}{M_p / M_c + .5} \qquad (2)$$

where M_p/M_p= projectile to propellant mass ratio

F. Muzzle velocity as a function of projectile mass, chamber pressure, propellant mass, chamber volume, tube diameter and tube length. (Vary projectile mass and tube diameter for optimized tube length and maximum cannon pressure.)

Figure 3.4

This parametric relationship attempts to get more specific with respect to projectile masses and muzzle velocities, and lumps the previous two cannon parametric relationships which were not shown. Unfortunately six independent variables are indicated to the one dependent variable of muzzle velocity. The first approach is to fix the cannon chamber pressure and tube length. The basis for this may be found in other parametric relationships which show tradeoffs in tube length and projectile accuracy, and tube length and chamber pressure in overall gun weight. Placing a boundary on these two parameters will reduce the proliferation of muzzle velocity curves which depend on them. Perhaps three pressures analyzed with respect to three tube lengths are sufficient for generating a trend in performance.

The relationship between the two independent variables of chamber volume and propellant mass may be reduced by maintaining a constant propellant loading density in the analysis. This may be justified by the need to maintain an optimum loading density to ensure smooth propellant burning in the chamber. With a constant loading density in the analysis, the chamber volume and propellant mass are allowed to grow until the maximum muzzle velocity is found for each projectile mass and tube diameter used. This peak in the muzzle velocity occurs because an optimum propellant grain design is reached for the chamber pressure, tube diameter, and projectile mass. Adding more propellant and chamber volume will then result in a reduction in muzzle velocity. These maximum muzzle velocities are graphed with respect to projectile mass and tube diameter, for a given propellant loading density and propellant type, cannon pressure, and tube length.

The draw back to this analysis is that the maximum muzzle velocity may not be the most practical design muzzle velocity for the cannon. Analysis has shown that the maximum muzzle velocity is reached with very large chamber volumes and propellant weights. The limitations of these parameters show up in overall gun weights and turret volumes and in the logistics of the ammunition. Therefore, the chamber volume should be bounded in the analysis by parametric relationships supplied by other system considerations. Then it becomes a simple procedure to limit the size to which the chamber may grow in the analysis. Figure 3.4 shows an example of the may interior ballistic tradeoffs which can be performed with the general parameters of the M256 120mm gun. This chart was developed using validated interior ballistic software.

G. Maximum rotational acceleration versus muzzle velocity, tube diameter, and rifling twist.

(not shown)

Projectile rotational acceleration is another important parameter to the projectile structural designer, and it is a result of launch system characteristics. The maximum rotational acceleration occurs at the gun tube muzzle and at the maximum projectile diameter:

rotational velocity $V_r = V_m \tan(\text{twist angle})$ **(3)**

normal (rotational) acceleration $A = V_r^2/\text{radius}$ **(4)**

H. Projectile dispersion versus rotational velocity and tube length.

(not shown)

The purpose of this parametric relationship is to place a boundary on gun tube lengths. Theoretically, there is much to gain in muzzle velocity by going to longer gun tubes. However, in practice other phenomena, based partially on tube length and elasticity, and any projectile in-bore misalignment introduce inaccuracies in the projectile system.

I. Average (or maximum) recoil force versus recoil length and muzzle energy.

(not shown)

This is an important parameter for the launch system integrators for chemical propulsion and EM/EM-ET guns. The maximum recoil force defines the trunnion design which contributes to weight and volume in the launch platform. Recoil length also requires a free recoiling distance behind the cannon. Postulated here is that the recoil mechanism dissipates the recoiling cannon kinetic energy through the work of a constant or variable force: $E = F\ Dx$. The recoiling cannon kinetic energy is based on the conservation of momentum of the projectile at the muzzle velocity plus a considerable contribution of the mass and velocity of the exiting propellant gasses.

J. Gun weight versus maximum pressure and tube diameter (for a given tube length).

(not shown)

This is another parametric relationship which integrates the launch system with the platform. The relationship is broken into parameters relevant to both the platform and launch system designer. The assumption made here is that the maximum pressure and tube diameter define a chamber volume. Although as seen in item F above, the optimized chamber volume is related to a specific projectile mass. For this application some sort of simplification is necessary. The maximum chamber pressure also does not fully describe the pressure along the gun tube, which is necessary for its structural design. A simplification will be required here as well. Different material properties should be examined and appropriate graphs developed.

Figure 3.1(a)
Launch Velocity vs Projectile Mass and Muzzle Energy

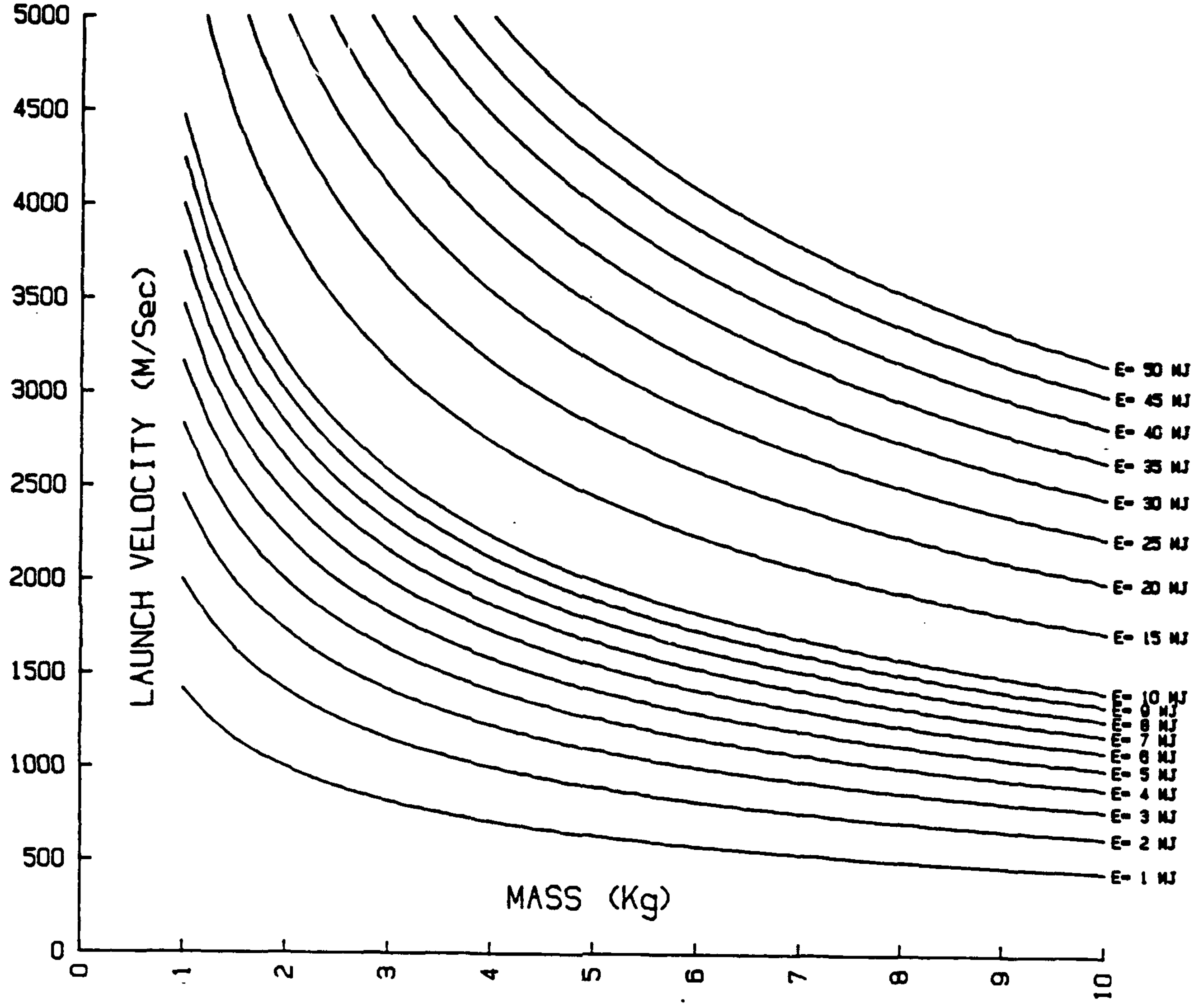


Figure 3.1(b)
Launch Velocity vs Projectile Mass and Muzzle Energy

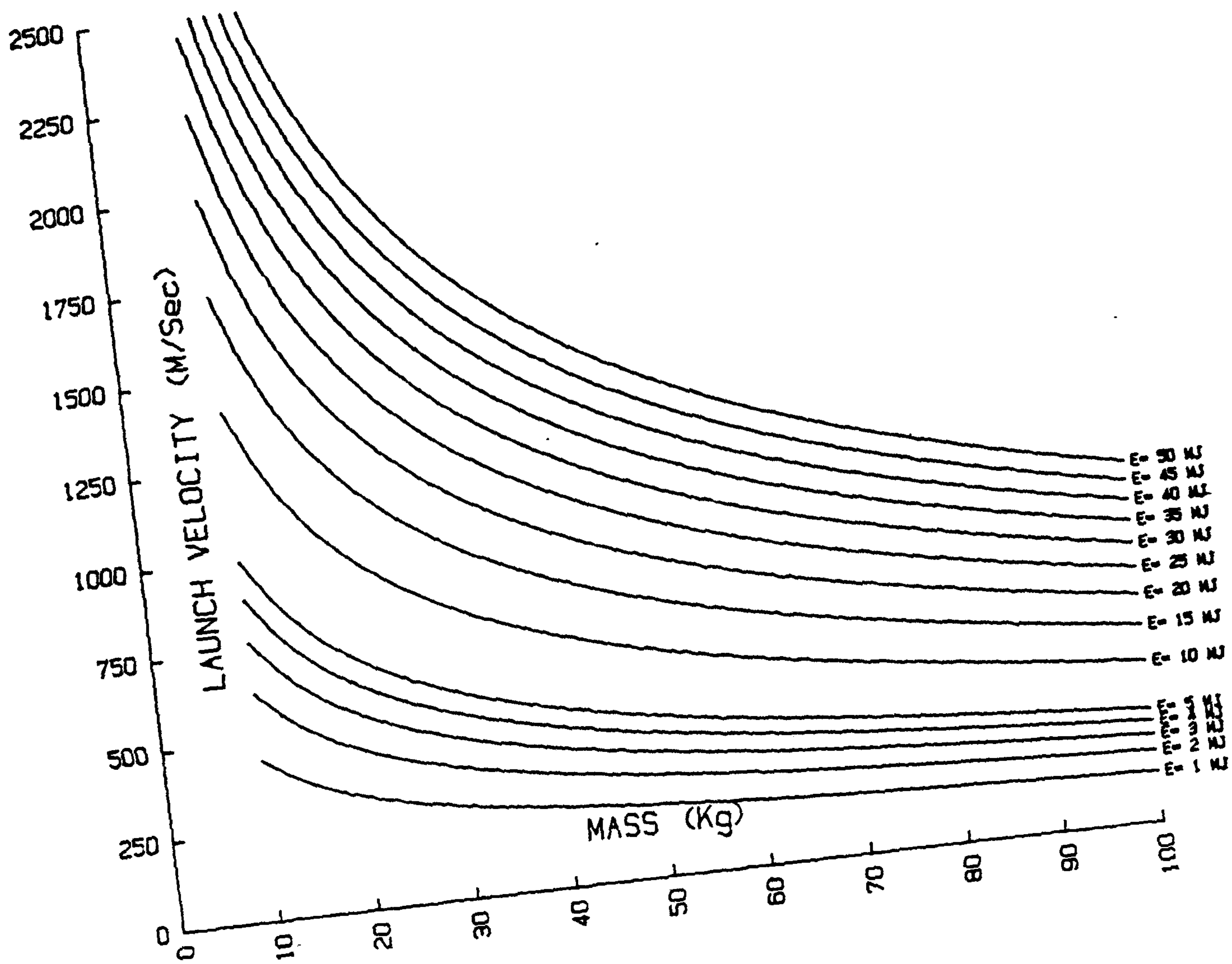


Figure 3.2
Sabot Ramp Mass vs Penetrator Mass and L/D

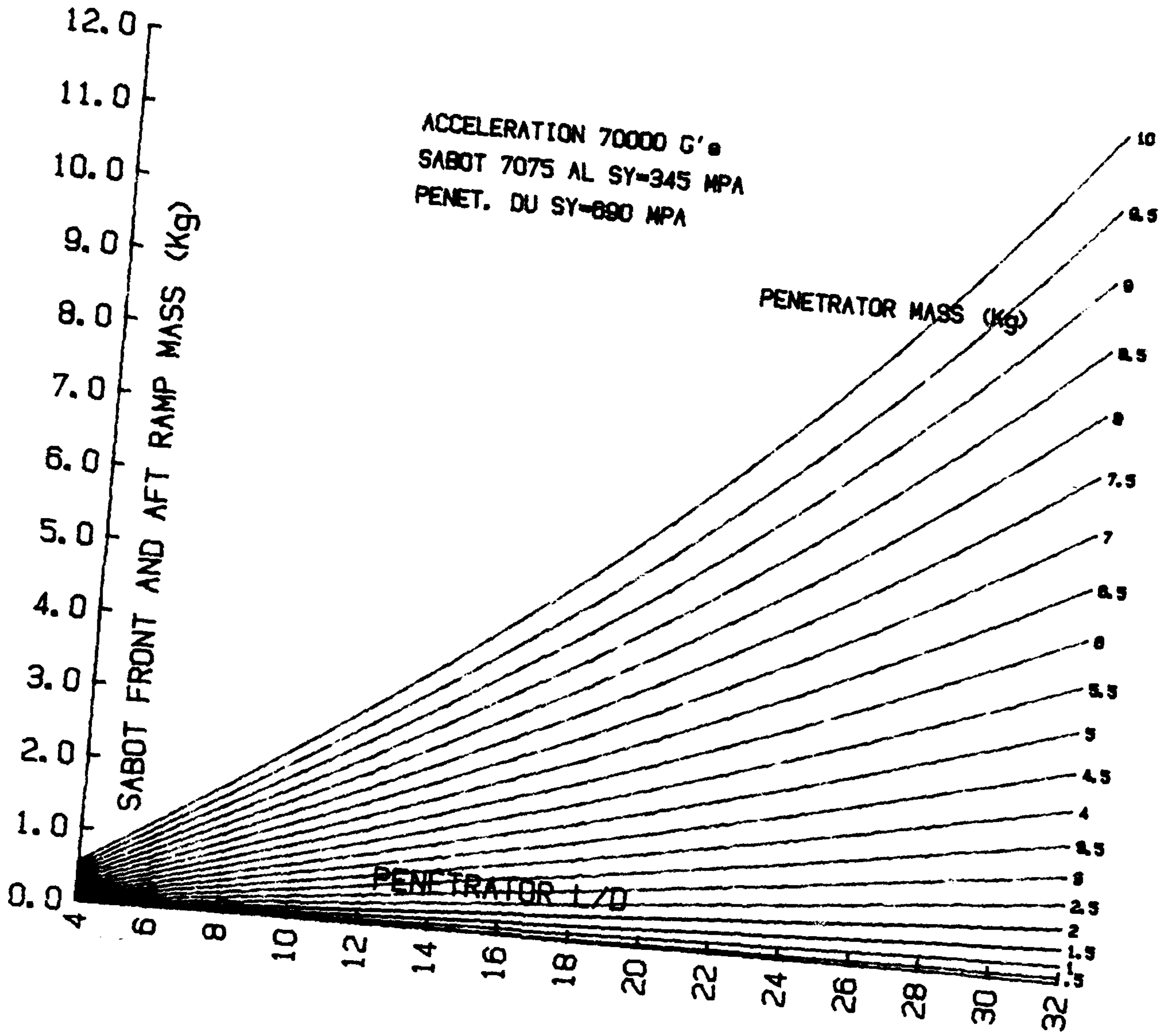


Figure 3.3
Total Sabot Mass vs Sabot Ramp Mass and Gun Diameter

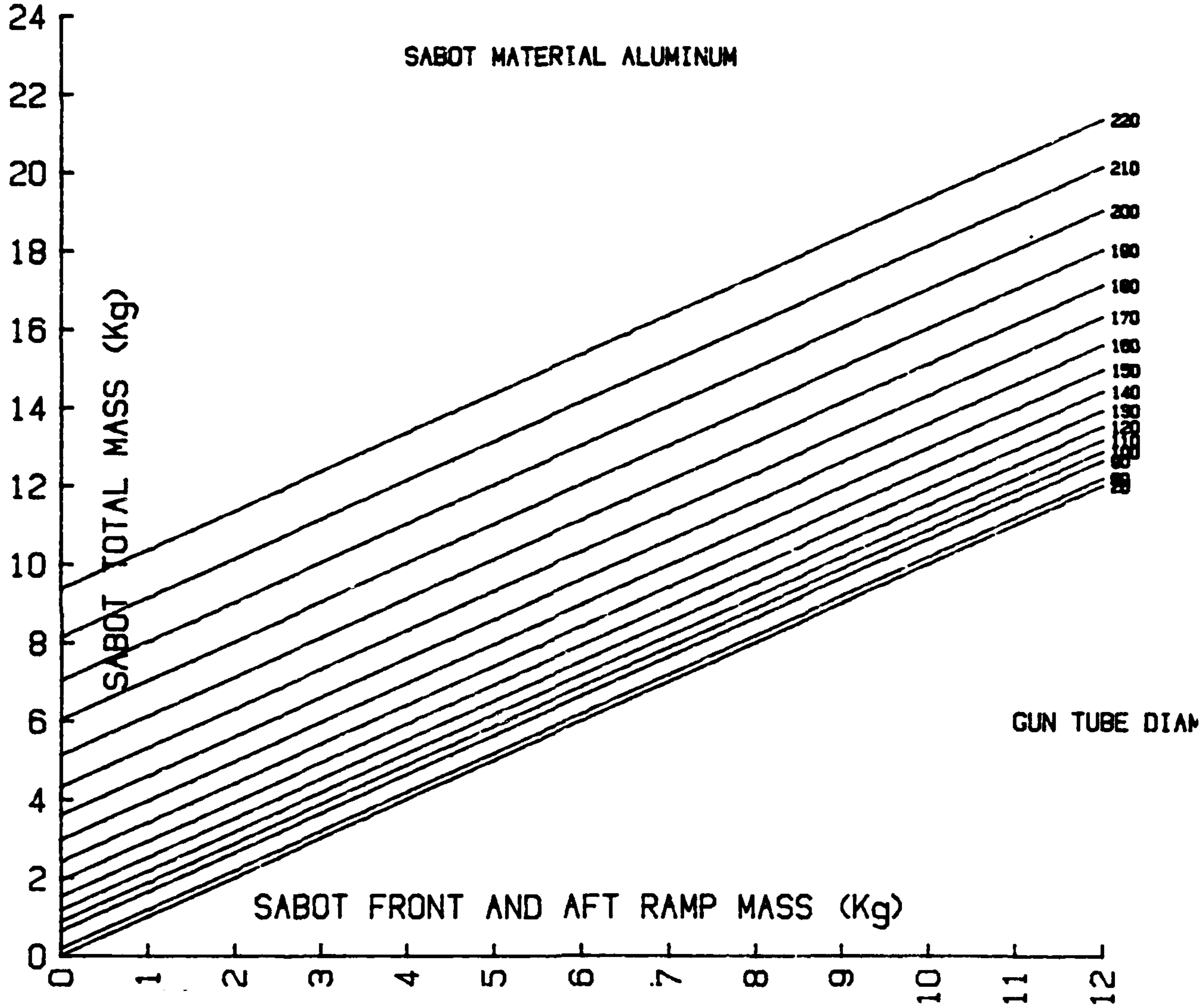
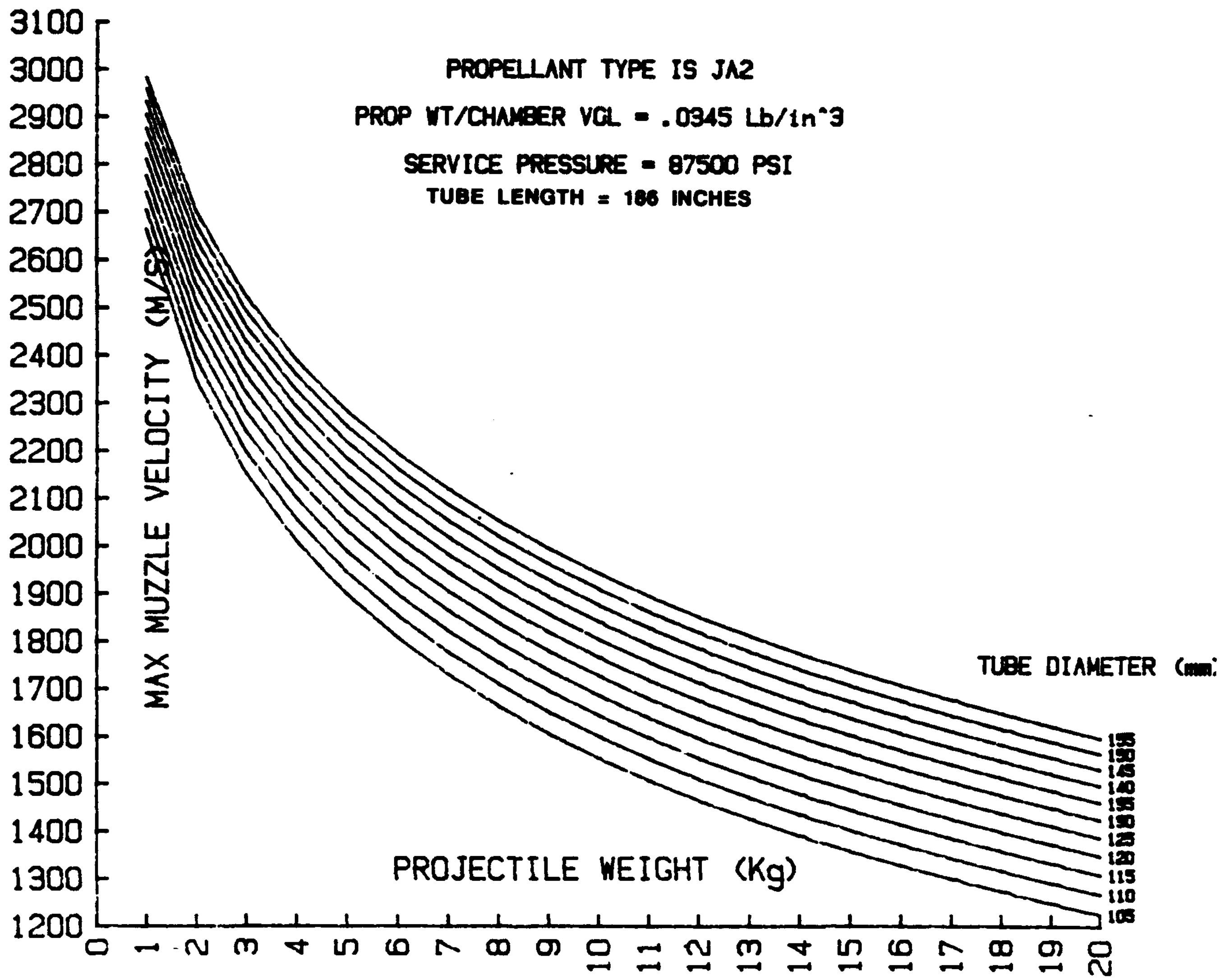


Figure 3.4
Muzzle Velocity vs Gun and Propellant Parameters



4. CONVENTIONAL ROCKET SYSTEM PARAMETRIC TRADEOFFS

These are first order approximations of those parametric relationships which are relevant to rocket and missile designers. They are all graphed and a short discussion is given on the derivation. The variables have been chosen in terms of the general parameters of launch systems, such as velocity, volume, and weight to allow comparisons between EM and conventional cannon systems.

A. Motor case weight versus motor volume and volume L/D

Figure 4.1 (a), (b), (c), (d)

The geometry of the propellant grain will affect the parasitic weight of the motor case, and ideally this weight should be minimized in the rocket. The thickness of the case and, hence, its weight is directly proportional to the operating pressure so an upper limit must be established here to maintain efficiency of the rocket. A lower pressure limit is also required to ensure smooth combustion of the propellant grain during all operating temperatures. 2000 psi was chosen as one reasonable operating pressure. Other pressures should be analyzed in addition to this one depending on the propellant used. These graphs show the tradeoffs for three materials -- steel and graphite fiber reinforced composite case materials. The following analysis formed the basis for these graphs.

Assuming the motor case to be a thin walled pressure vessel, the hoop stress is:

$$S_h = PD/2t \qquad (5)$$

where P = design pressure
D = case internal diameter
t = case thickness

the longitudinal stress (ends are capped) is:

$$S_l = PD/4t \qquad (6)$$

applying the Von Mises yield criteria for an isotropic material and using the resultant stress:

$$S_r = \frac{1}{\sqrt{2}} \bullet \left[S_l^2 + S_h^2 + (S_l - S_h)^2\right]^{1/2} \tag{7}$$

yields:

$$S_r = PD/2t \tag{8}$$

or the hoop stress is the critical stress in the case.

Setting the material yield stress (Sy) equal to the resultant stress gives the case design thickness to internal diameter:

$$t/D = P/2S_y \tag{9}$$

and

$$Vol = \frac{\pi D^3}{4} \bullet \left(\frac{L}{D}\right) \tag{10}$$

This is plotted for the example materials under consideration.

The use of fiber reinforced graphite epoxy composite offers considerable weight savings. Such a motor case can be manufactured using filament winding machines and pressure ovens. The approximate strength of this material in a quasi-isotropic layup (fibers running +45,90,-45,0 in the directions of the skin surface) is 100,000 psi. This layup was chosen for convenience, but others are also possible.

B. Thrust versus grain burning surface and chamber pressure

Figure 4.2 (a), (b)

The thrust which a rocket can deliver is a function of the motor chamber pressure, the propellant grain burning surface, and the propellant burning characteristics. The specific propellant characteristics are the burning rate versus pressure, the ratio of specific heats of the product gases, gas temperature, gas constant R, and the grain density. For this reason the graph must be prepared for each propellant studied.

M1 propellant was chosen here for convenience. The additional assumption of a full expansion nozzle is used, where the exhaust pressure equals atmospheric pressure. This maximizes thrust potential. One warning to this is that nozzle weight is also maximized, which represents an additional tradeoff when designing a rocket.

The governing equations for thrust are[4]:

$$Thrust = A_t P \left[\left(\frac{2\gamma^2}{\gamma - 1} \right) \left(\frac{2}{\gamma + 1} \right)^{(\gamma+1)/(\gamma-1)} \left(1 - \left(14.7/P \right)^{(\gamma-1)/\gamma} \right) \right]^{1/2} \tag{11}$$

where A_t = nozzle throat area
P = chamber pressure
γ = combustion gas ratio of specific heats
$A_t = A_b/K$ where A_b = grain burning surface

and

$$K = \frac{P^{(1-n)} \left[\gamma \left(2/(\gamma + 1) \right)^{\left[(\gamma+1)/(\gamma-1) \right]} \right]^{1/2}}{\rho A_1 \sqrt{gRT}} \tag{12}$$

where A_1 = burning rate coefficient
n = burning rate exponent
ρ = mass density of propellant
g = gravity
R = gas constant
T = gas temperature

---

4 *Design of Aerodynamically Stabilized Free Rockets*, AMC Pamphlet 706-280, U.S. Army Material Command, July 1968.

C. Burn time versus grain diameter and chamber pressure

Figure 4.3

Burn time is a motor characteristic equally important as thrust, since together they define the total impulse which the motor will provide. Burn time is proportional to the effective grain burning thickness, and chamber pressure. Propellants burn at different rates for different pressures so several chamber pressures are analyzed. The governing burning rate equation is: $r = A_1 P^n$ inches per second.

Propellants burn at their surface and through their thickness. Therefore, a grain geometry must be defined. For motor weight efficiency, a constant pressure is desirable, so a neutral burning surface grain geometry is employed. One neutral surface geometry is the rod-in-tube. The burning surface is the longitudinal outer surface of the internal rod plus the corresponding inner longitudinal surface of the surrounding tube. Both rod and tube are concentric within the rocket motor. As the rod burns inward, the tube burns outward and the combined surface remains constant. The effective burning thickness is the grain diameter divided by four. Other possible neutral burning geometries include the internal star and an end burning grain.

D. Grain burning surface versus motor volume and L/D.

Figure 4.4 (a), (b)

The grain burning surface, which defines the rocket thrust is a function of the grain L/D and the grain volume. These last two parameters also define the rocket motor case weight. Again, for efficiency of the motor case, a neutral burning grain geometry is chosen and the burning surface for both the rod-in-tube and internal star is: $S = \pi D L$.

E. Motor impulse versus propellant weight and chamber pressure

Figure 4.5 (a), (b)

This parameter begins to define the rocket performance characteristics. It was observed that thrust increases for increasing burning surface and that burn time is related to grain thickness and pressure. It follows that an important relationship is the total motor impulse with respect to the geometry of a constant volume of propellant. If thrust increases because surface area increases, then for a constant propellant volume or weight, the diameter must decrease and hence the burning time will decrease. What will then be the effect on total impulse, which is the product of thrust and time?

Hypothesizing that a mass of propellant can only release one maximum amount of energy regardless of its physical geometry leads to the definition of a parameter called the propellant specific impulse. This is, in fact, true and it relates the burning rate equation to the thrust equation from above, and yields the impulse for a given propellant type and mass:

$$I = M\left[gRT\left(\frac{2\gamma}{(\gamma-1)}\right)\left(1-\left(\frac{14.7}{P}\right)^{(\gamma-1)/\gamma}\right)\right]^{1/2} \tag{13}$$

As seen in the equation, it is slightly dependent on chamber pressure, and that is shown in the plot. However, since the spread is very small, specific impulses are defined for propellants and allow a quick comparison of performance per propellant weight.

F. Zero-Drag burnout velocity versus propellant weight and chamber pressure.

Figure 4.6

Combining the previous five relationships yields a design parameter for rocket velocity and weight. Zero-drag burnout velocity is a simple and valid characteristic for relative comparisons between designs, and if burn time is very short, drag effects become negligible during boost, and comparisons to other launch systems, such as cannons, can be made directly.

Combining the grain burning rate equation, which describes the mass flow rate, or the decrease in rocket total weight over time, with the thrust equation yields the zero-drag burnout velocity:

$$V_{ideal} = \frac{I}{M_p} \ln\left(\frac{M_o}{M_o - M_p}\right) g \qquad (14)$$

and introducing the propellant weight fraction:

weight fraction (% 100) = M_p/M_o

yields:

$$V_{ideal} = I_{sp} \ln\left(\frac{M_o/M_p}{M_o/M_p - 1}\right) g \qquad (15)$$

This graph shows that propellants have a limiting maximum burnout velocity for reasonable weight fractions. Therefore, greater velocities and larger payloads can only be achieved with propellants of larger specific impulses (energy density), or through the use of multi-stage rockets, which shed no longer needed parasitic motor weight during flight.

Figure 4.1(a)
Motor Case Weight vs Motor Volume and L/d

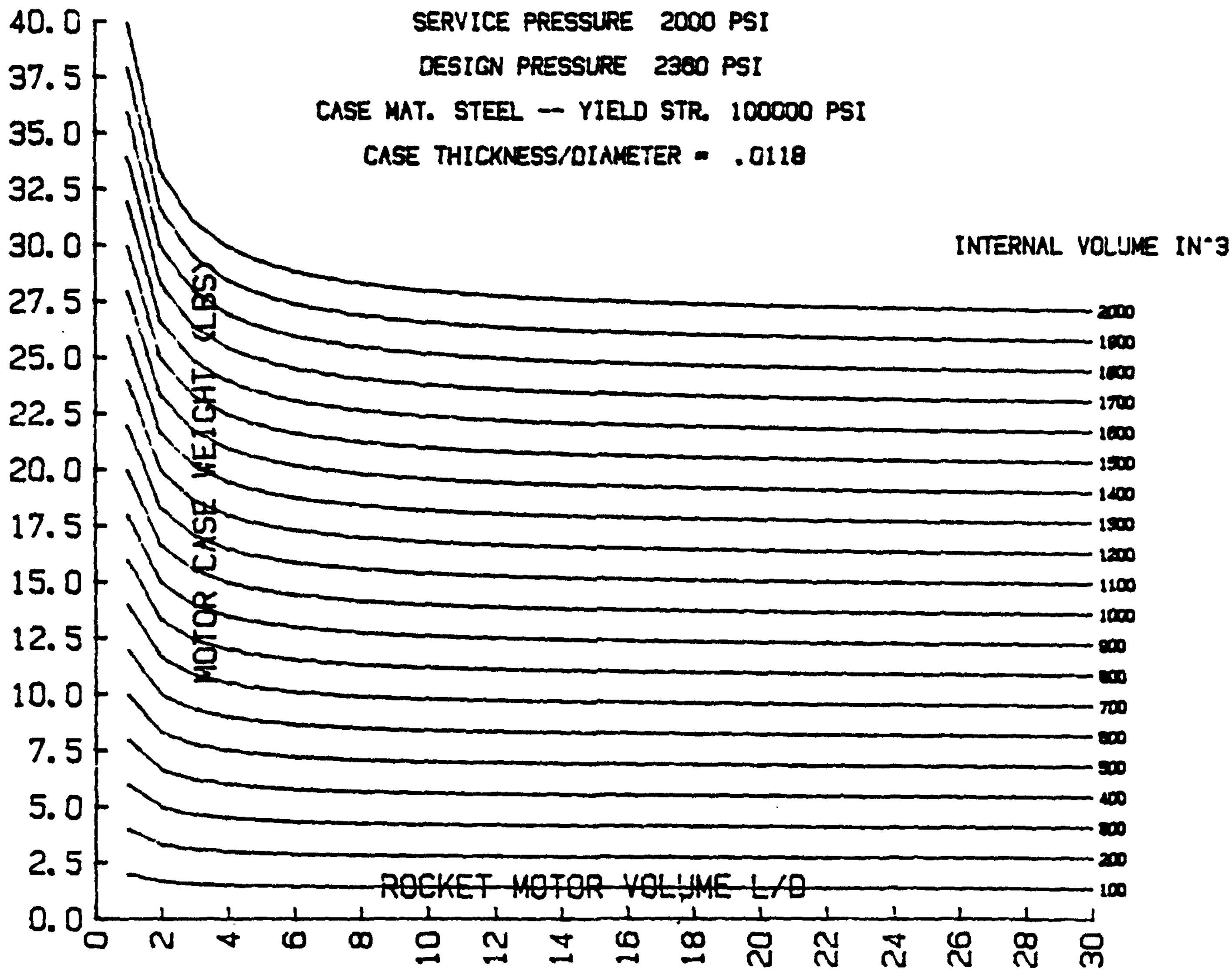


Figure 4.1(b)
Motor Case Weight vs Motor Volume and L/d

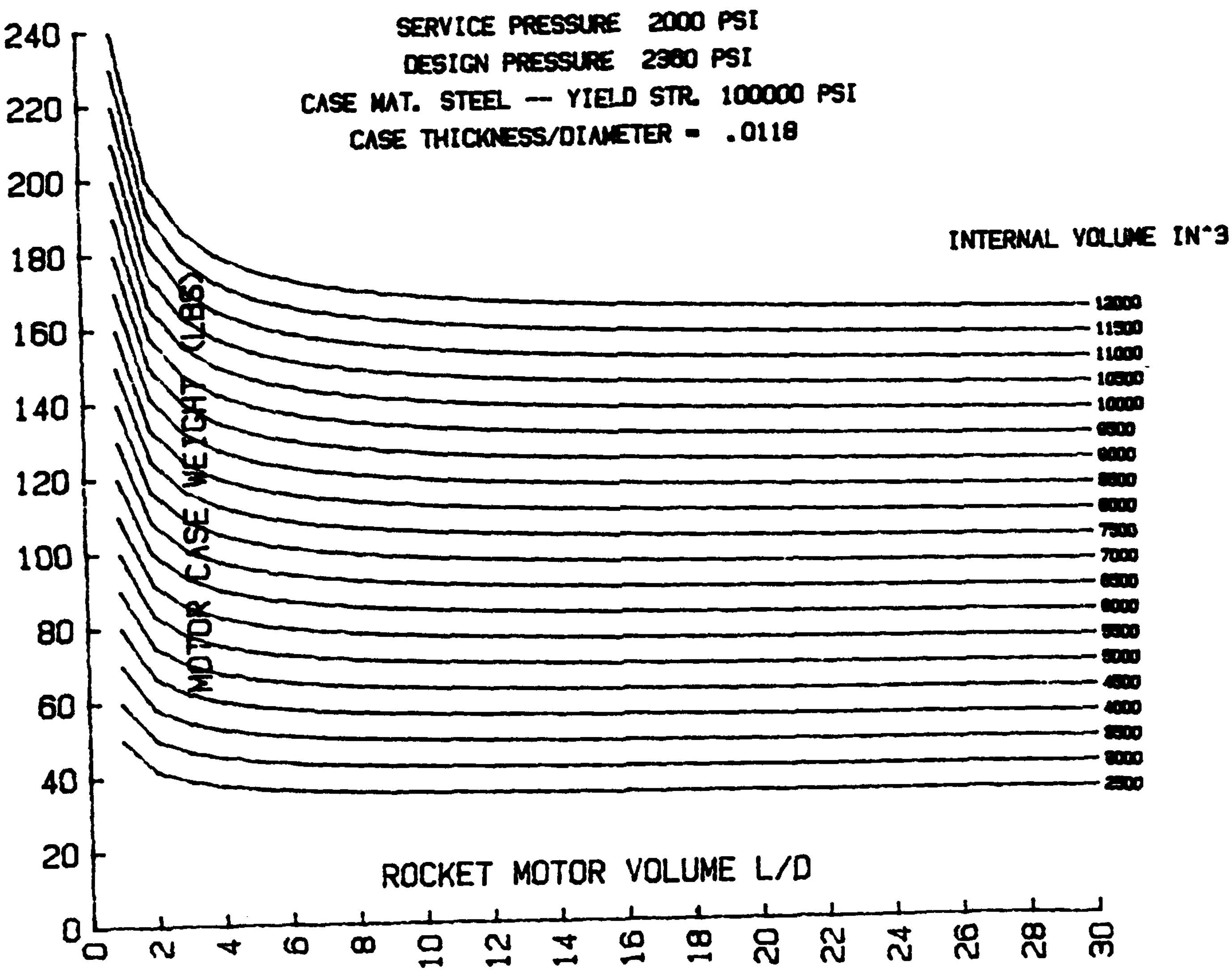


Figure 4.1(c)
Motor Case Weight vs Motor Volume and L/d

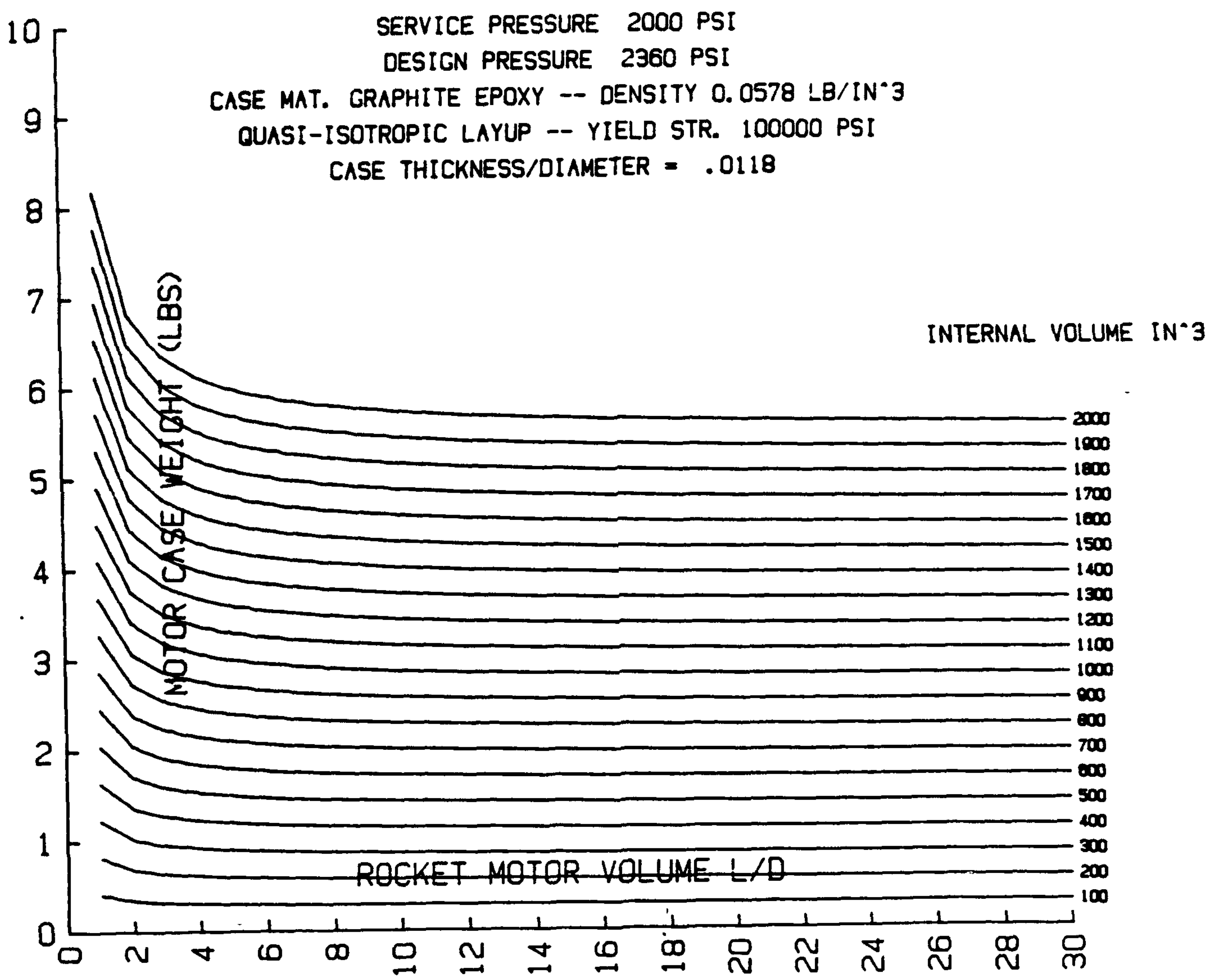


Figure 4.1(d)
Motor Case Weight vs Motor Volume and L/d

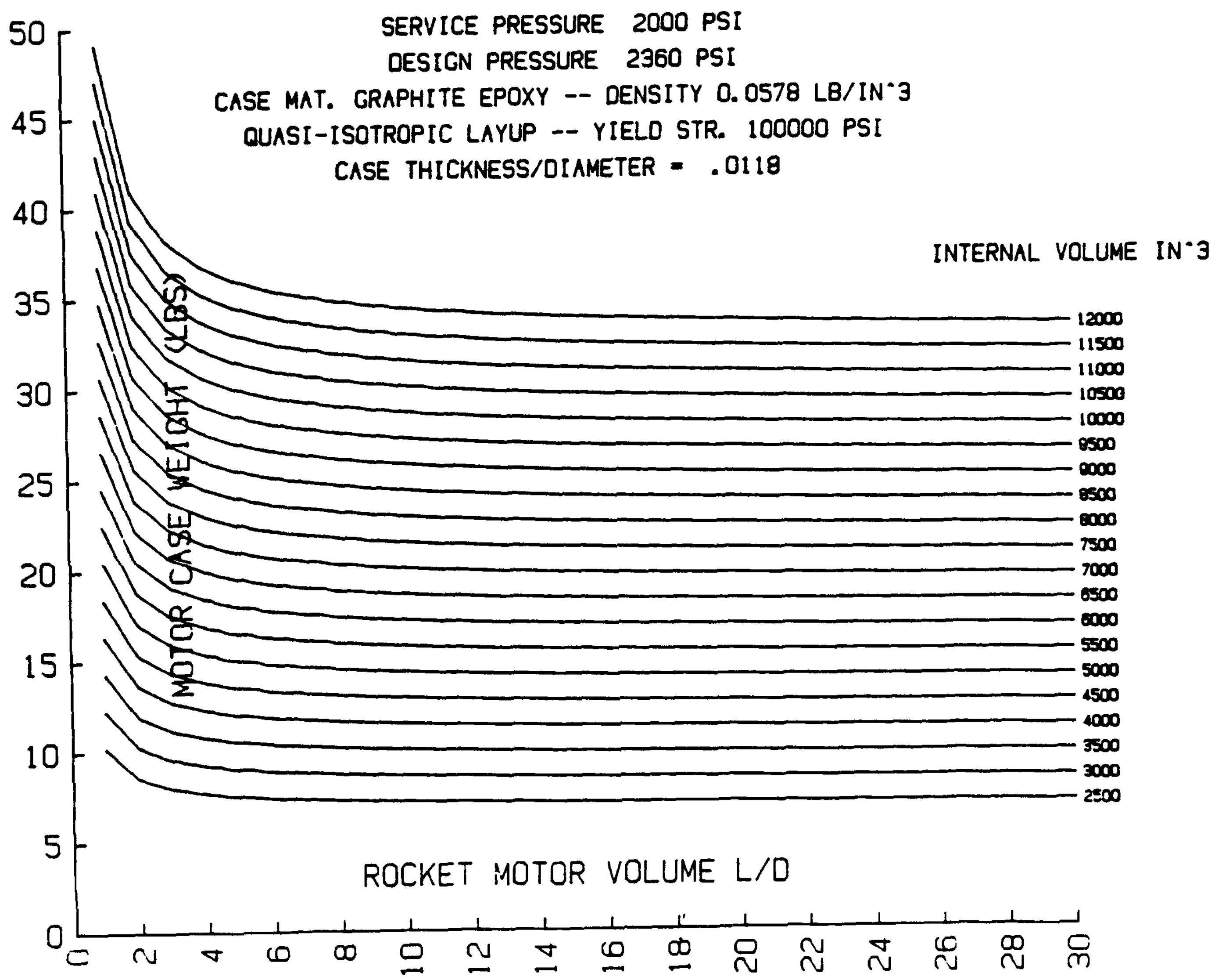


Figure 4.2(a)
Thrust vs Grain Burning Surface and Chamber Pressure

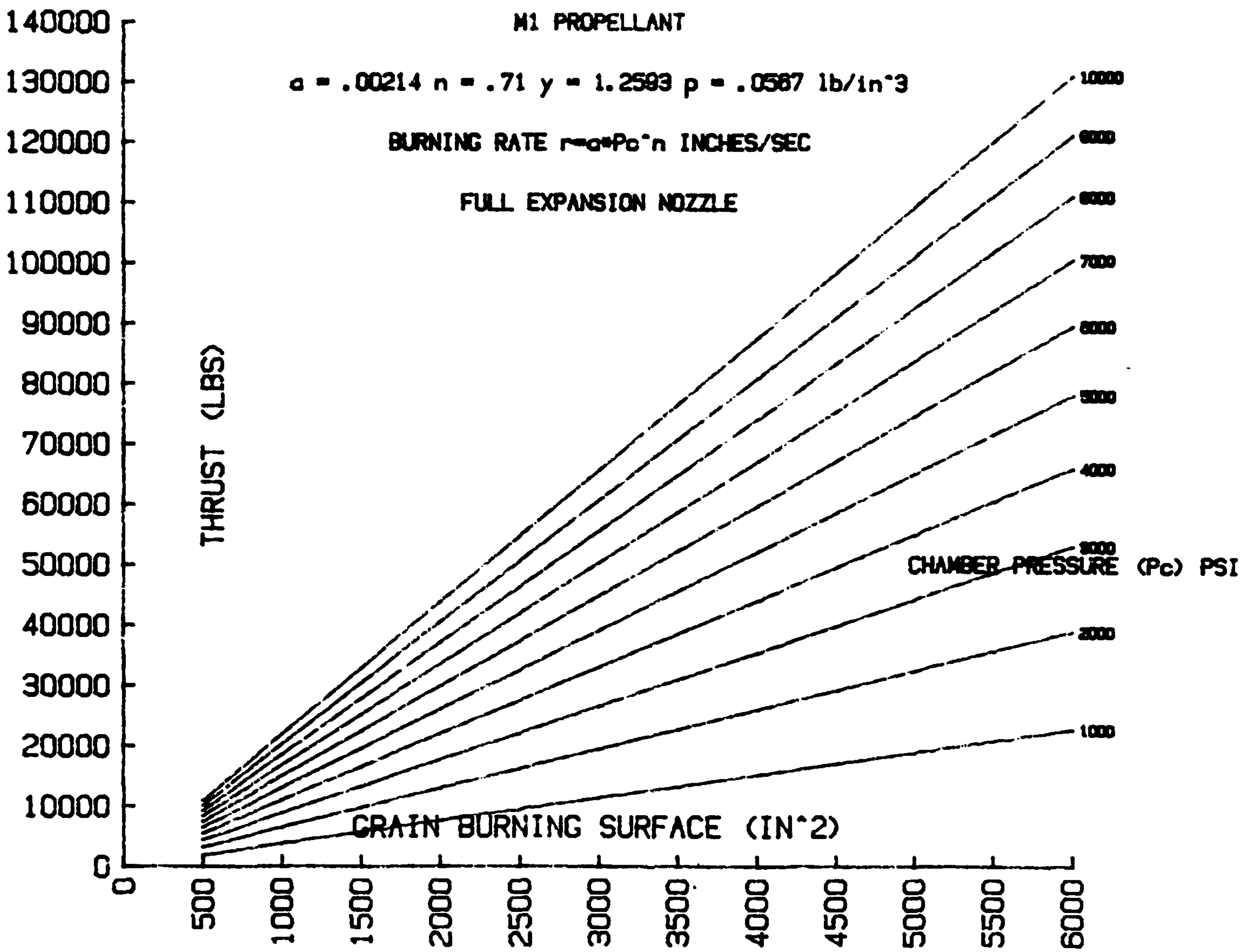


Figure 4.2(b)
Thrust vs Grain Burning Surface and Chamber Pressure

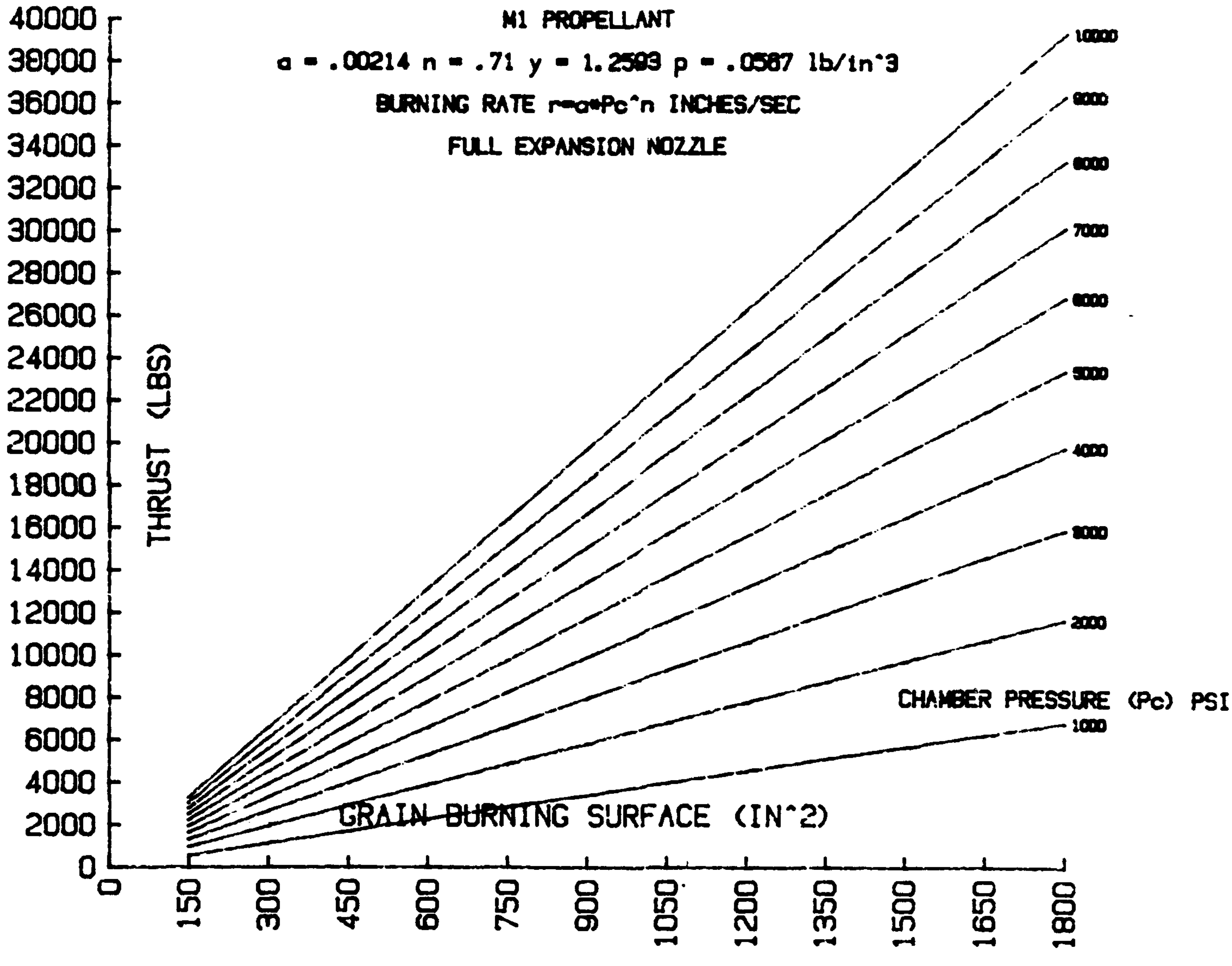


Figure 4.3
Burn Time vs Grain Diameter and Chamber Pressure

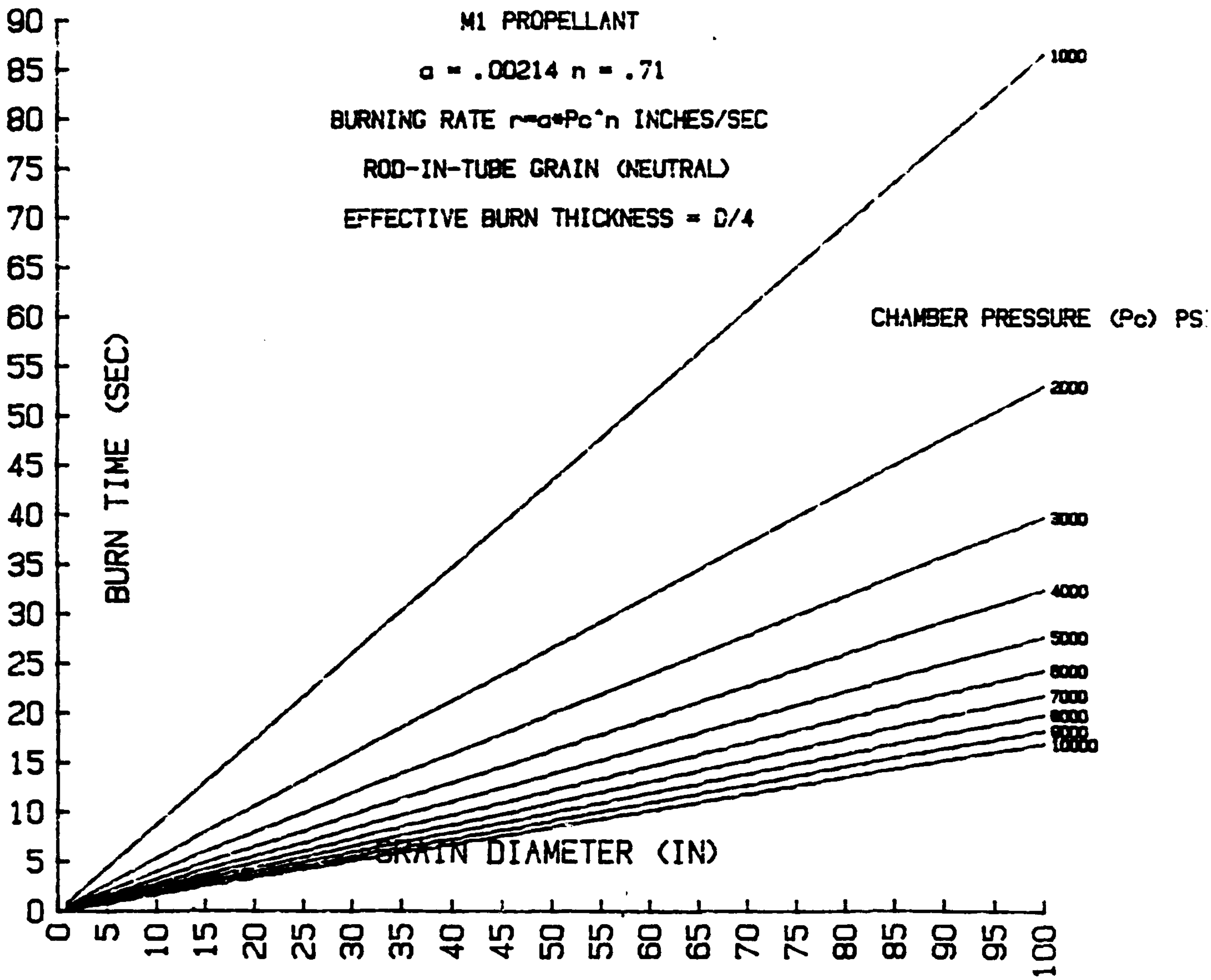


Figure 4.4(a)
Grain Burning Surface vs Motor Volume and L/D

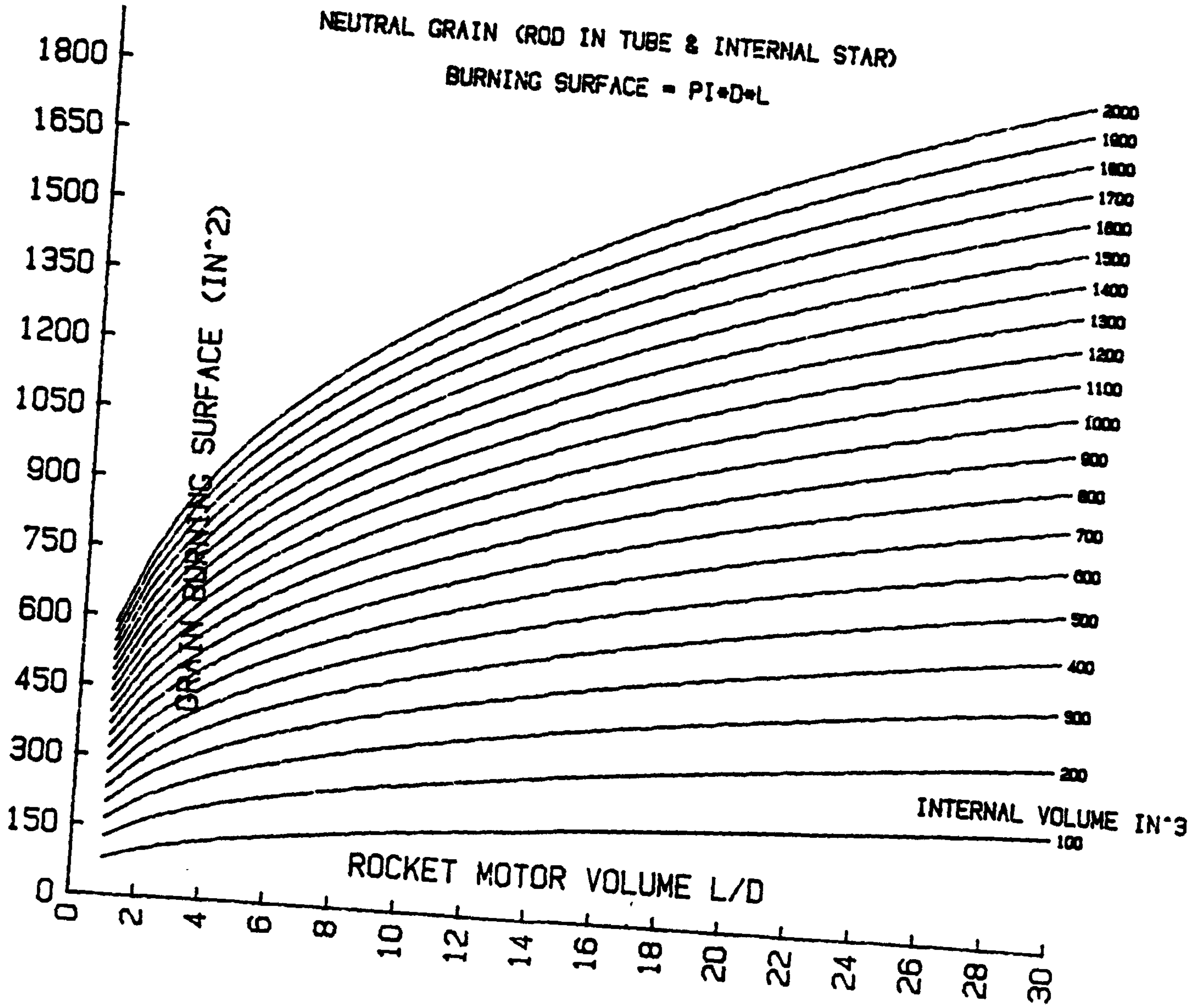


Figure 4.4(b)
Grain Burning Surface vs Motor Volume and L/D

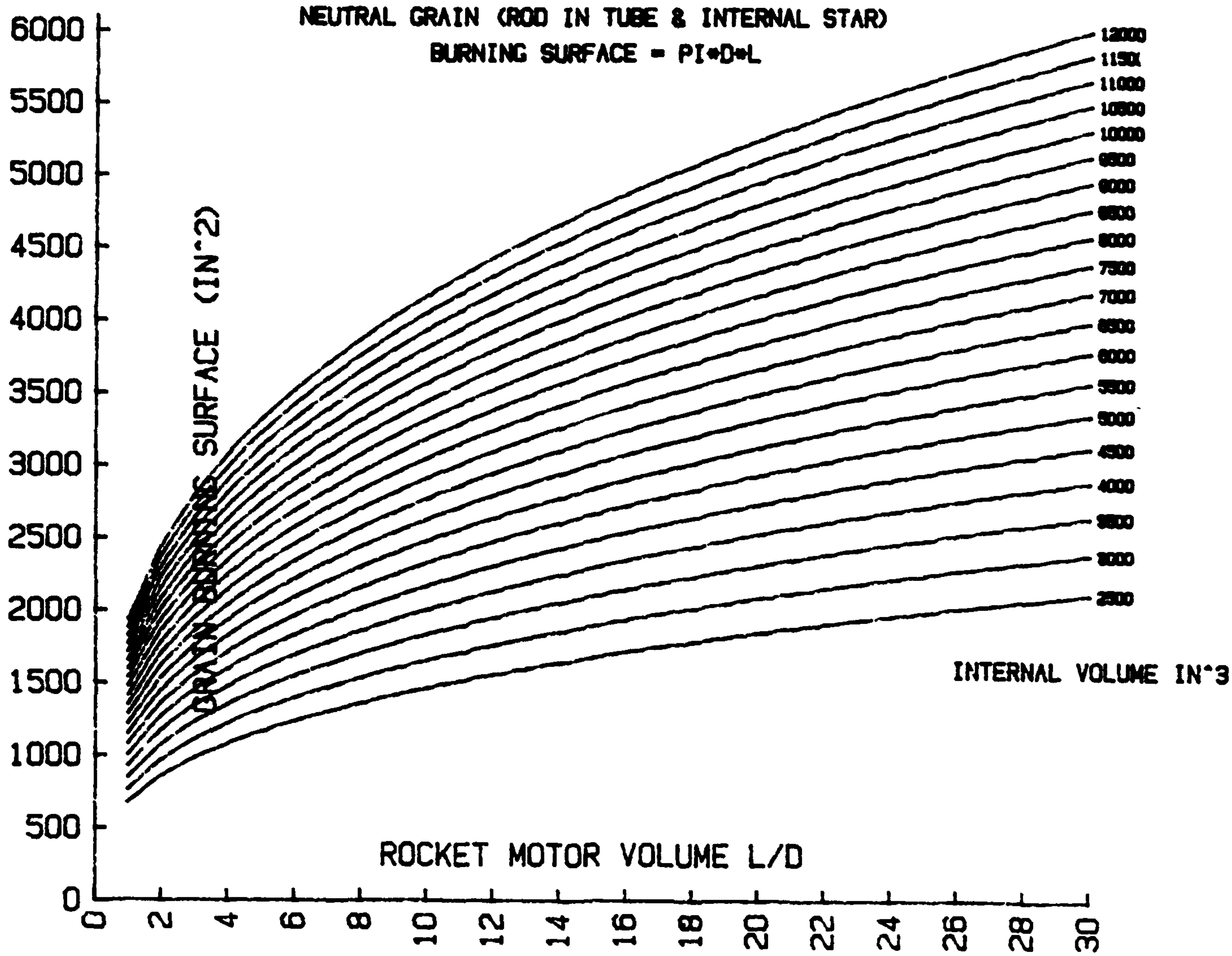


Figure 4.5(a)
Motor Impulse vs Propellant Weight and Chamber Pressure

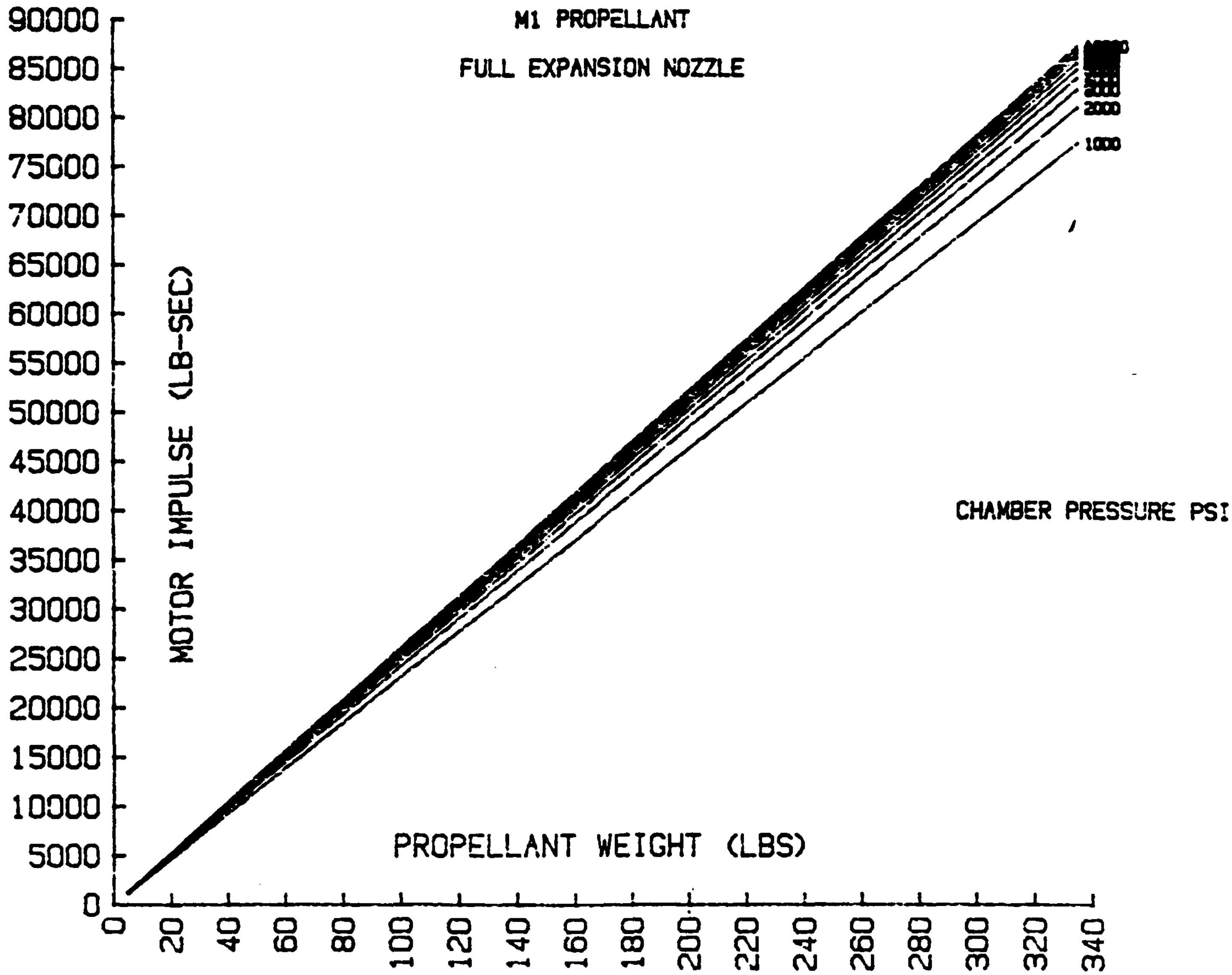


Figure 4.5(b)
Motor Impulse vs Propellant Weight and Chamber Pressure

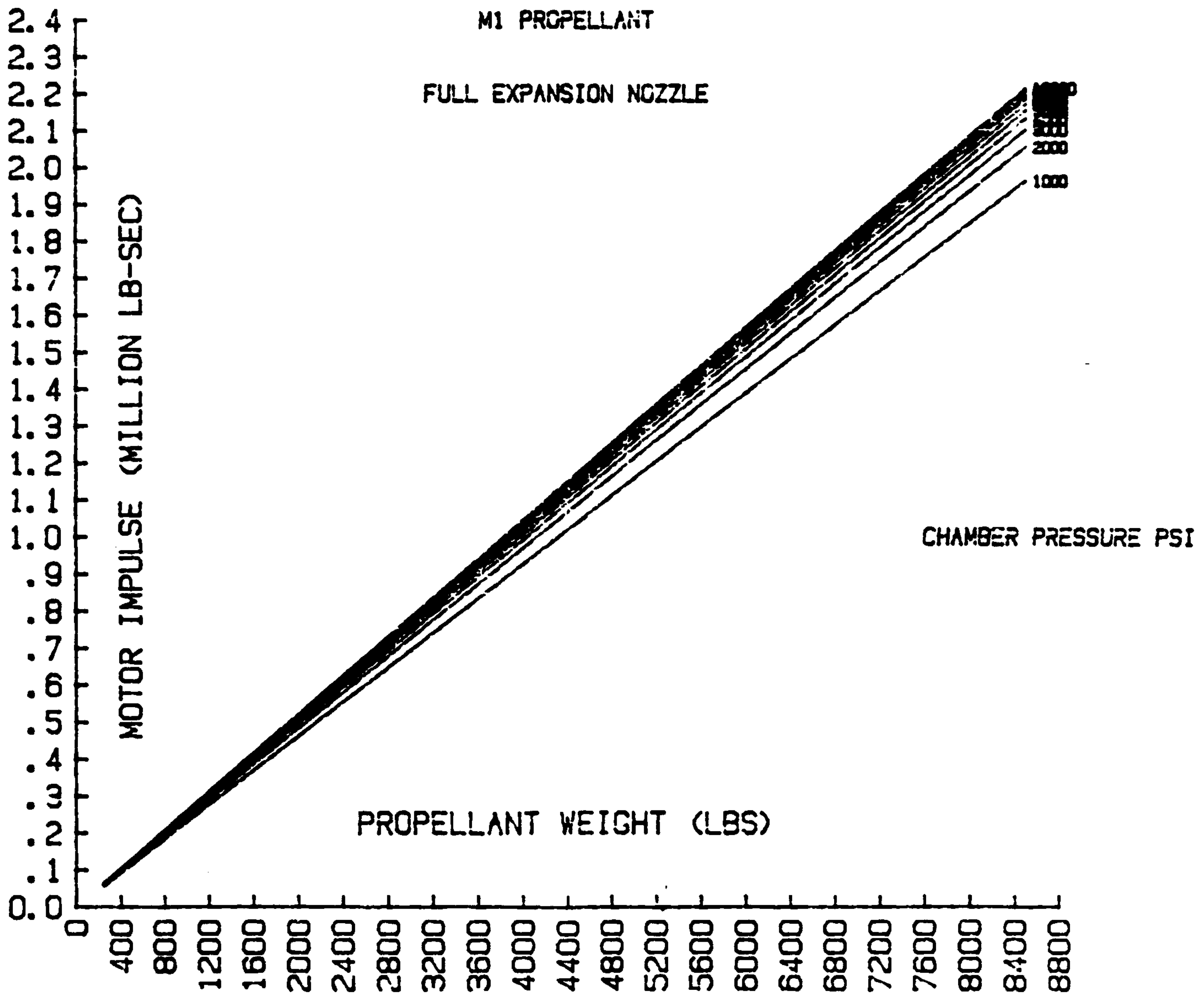
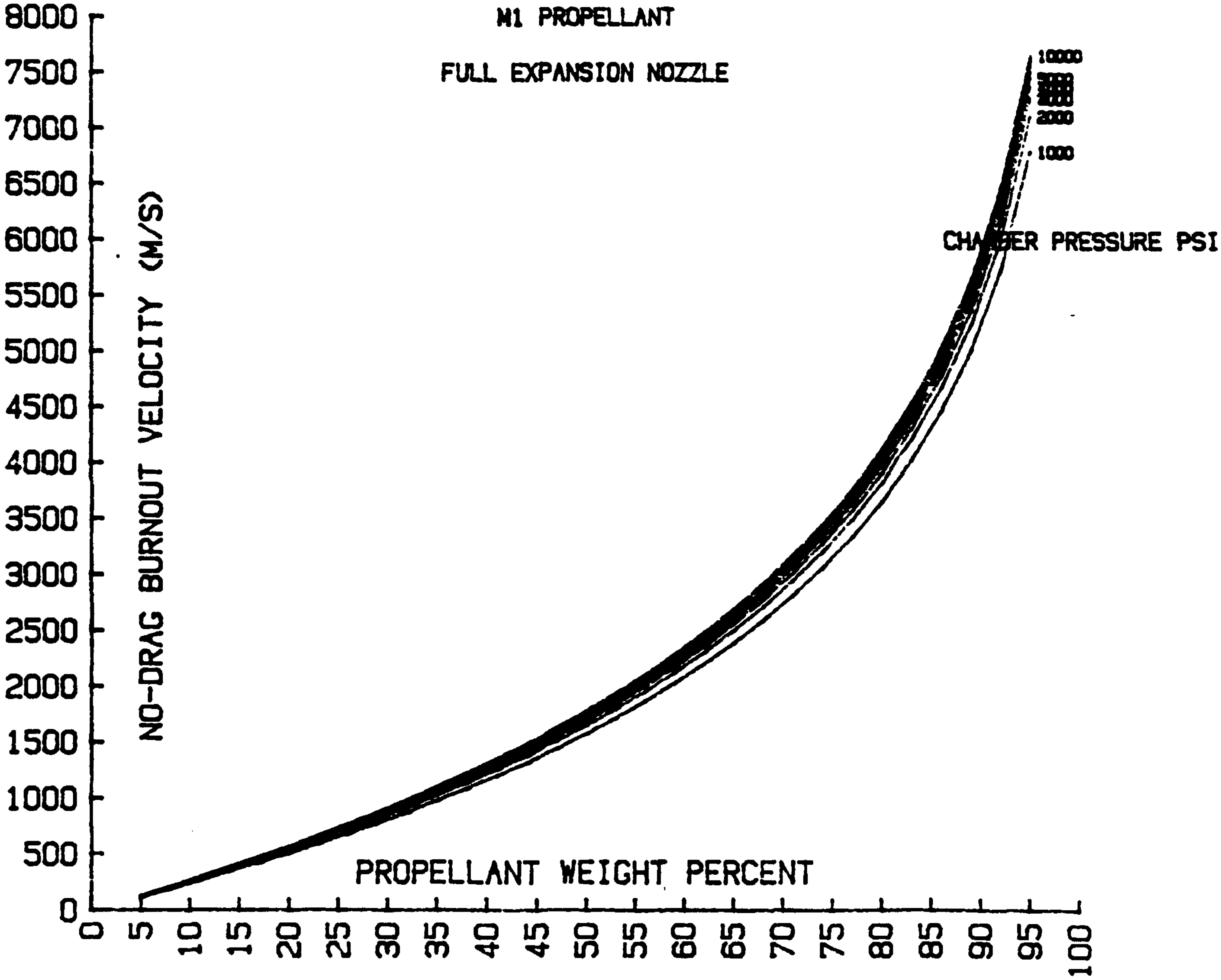


Figure 4.6
Zero-Drag Burnout Velocity
vs
Propellant Weight and Chamber Pressure



5. AERODYNAMIC PARAMETRIC TRADEOFFS

Aerodynamic parameters are applicable to both conventional cannon and rocket launch systems, as well as EM based propulsion mechanisms, since drag will affect maximum range and terminal velocity of any projectile package. This is significant for all three mission areas of anti-armor, fire support, and air defense, since target kill requirements demand some combination of range, terminal velocity, and warhead mass and volume.

A. Maximum range versus muzzle velocity and ballistic coefficient.

Figure 5.1 (a), (b), (c)

This parametric relationship is generated using a simple point mass trajectory through a standard atmosphere, with a constant projectile drag coefficient. It is not representative of any one system, but shows the tradeoffs between muzzle or burnout velocity, form factor, and mass. The projectile or missile is launched at 45 degrees elevation (flat earth assumed).

The ballistic coefficient of the projectile represents the combined aerodynamic drag effects on the projectile's inertia and is defined as the mass of the flight projectile divided by its cross sectional area and drag coefficient. The ballistic coefficient parameter makes the curves valid for any caliber projectile.

To put the ballistic coefficient parameter in perspective, the parameters of some known systems are approximately as follows:

M829 120mm KE projectile	- -	80,000 Kg/M^2
M59 7.62mm Bullet	- -	800 Kg/M^2
M107 155mm HE projectile	- -	9500 Kg/M^2

What is interesting to note from these relationships is that for extended range artillery applications, ever higher muzzle velocity ceases to be the governing parameter for achieving greater range. Projectile streamlining and weight quickly become the most important parameters, since very high muzzle velocity is very quickly eaten away by aerodynamic drag, if there is insufficient mass behind it. The following graphs show this tradeoff in the kinetic energy application.

B. Terminal velocity versus muzzle velocity and ballistic coefficient (at various target ranges).

Figure 5.2 (a) - (j)

This relationship is based on the same model as above. However, it shows terminal velocity of the projectile at ranges from 1000 to 10,000 meters. Trajectory elevation is flat, and sea level atmospheric conditions are assumed. Clearly, highly streamlined and heavy kinetic energy projectiles are required for the anti-armor mission.

Figure 5.1(a)
Maximum Range vs Muzzle Velocity and Ballistic Coefficient

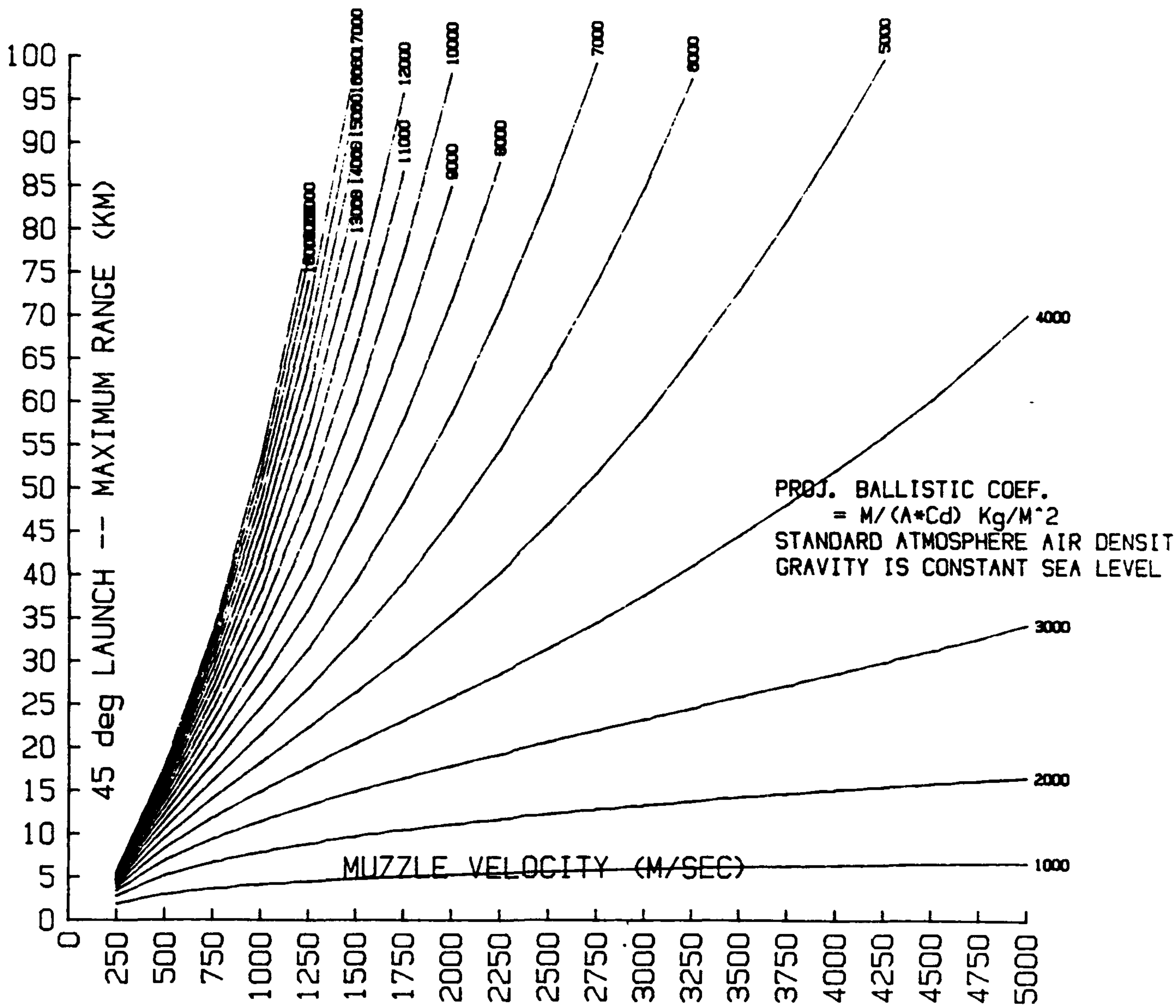


Figure 5.1(b)
Maximum Range vs Muzzle Velocity and Ballistic Coefficient

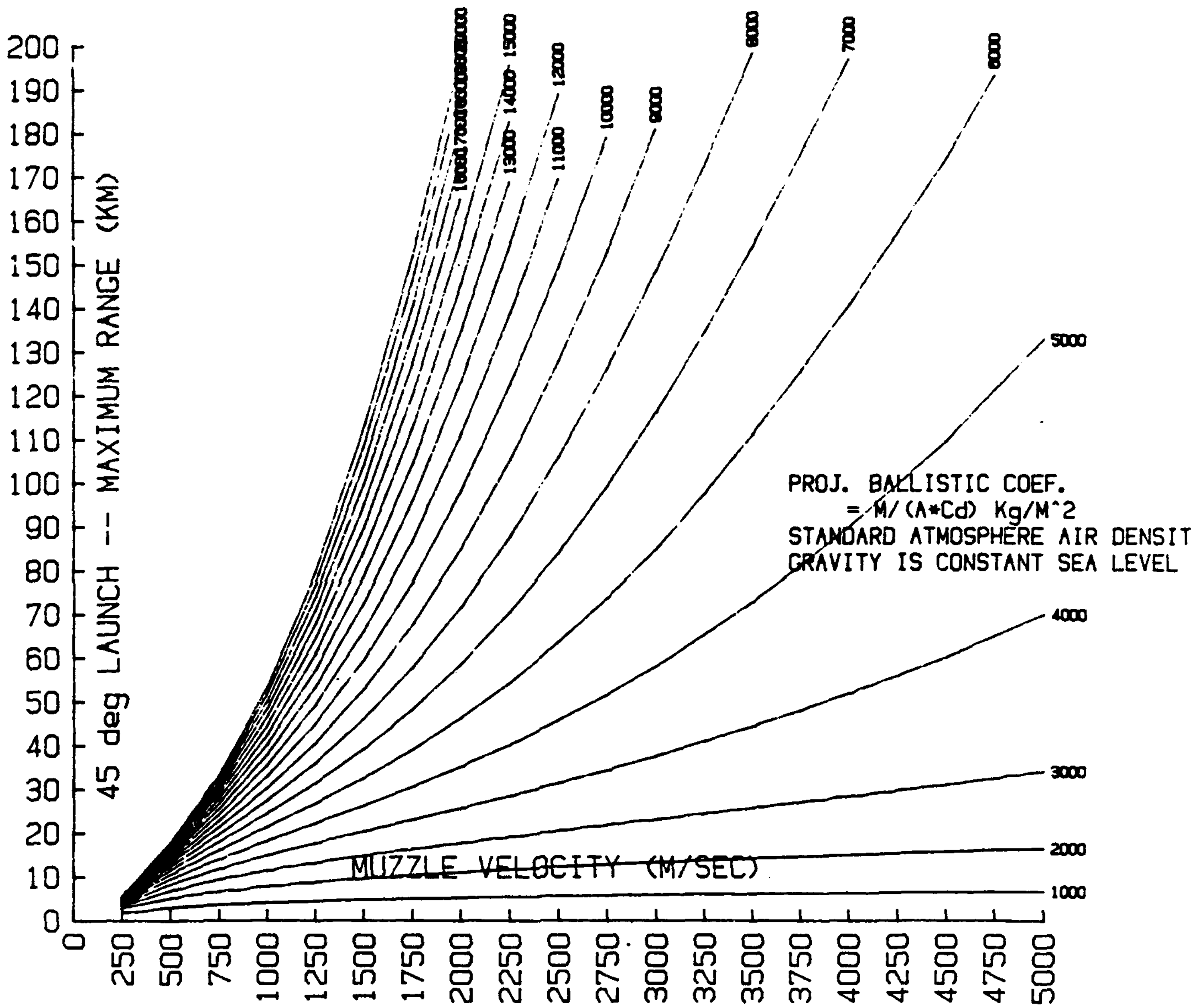


Figure 5.1(c)
Maximum Range vs Muzzle Velocity and Ballistic Coefficient

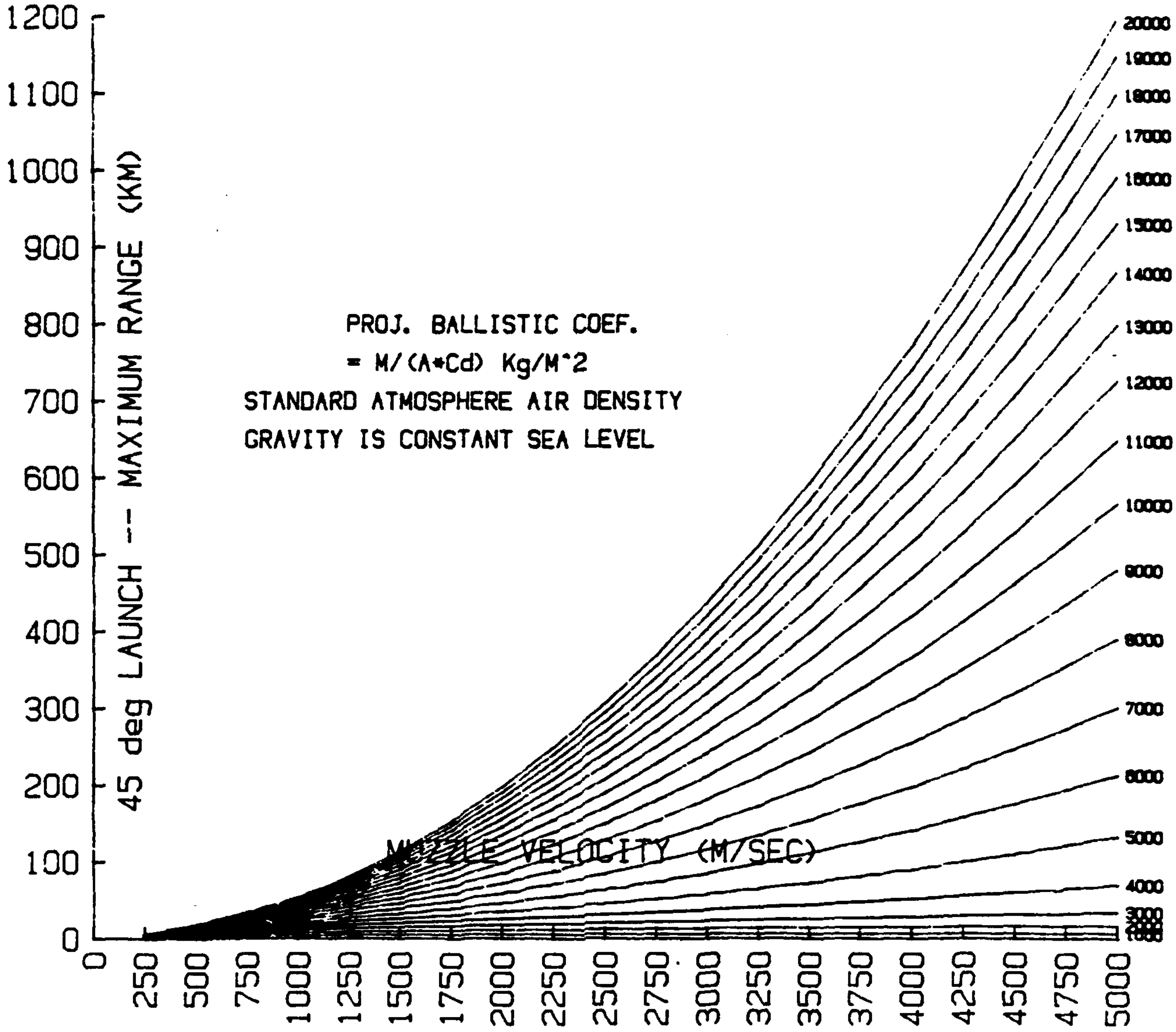


Figure 5.2(a)
Terminal Velocity vs Muzzle Velocity and Ballistic Coefficient

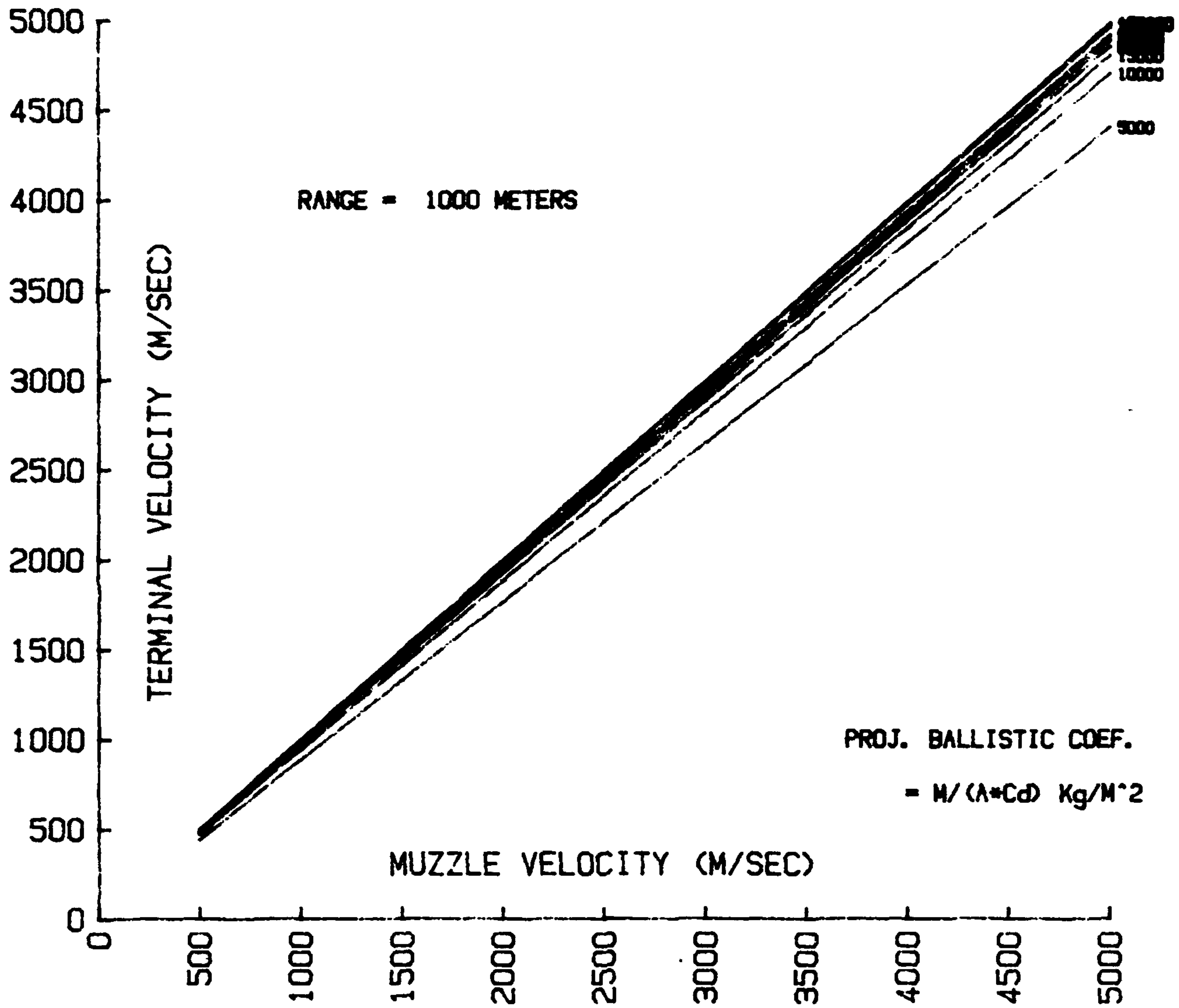


Figure 5.2(b)
Terminal Velocity vs Muzzle Velocity and Ballistic Coefficient

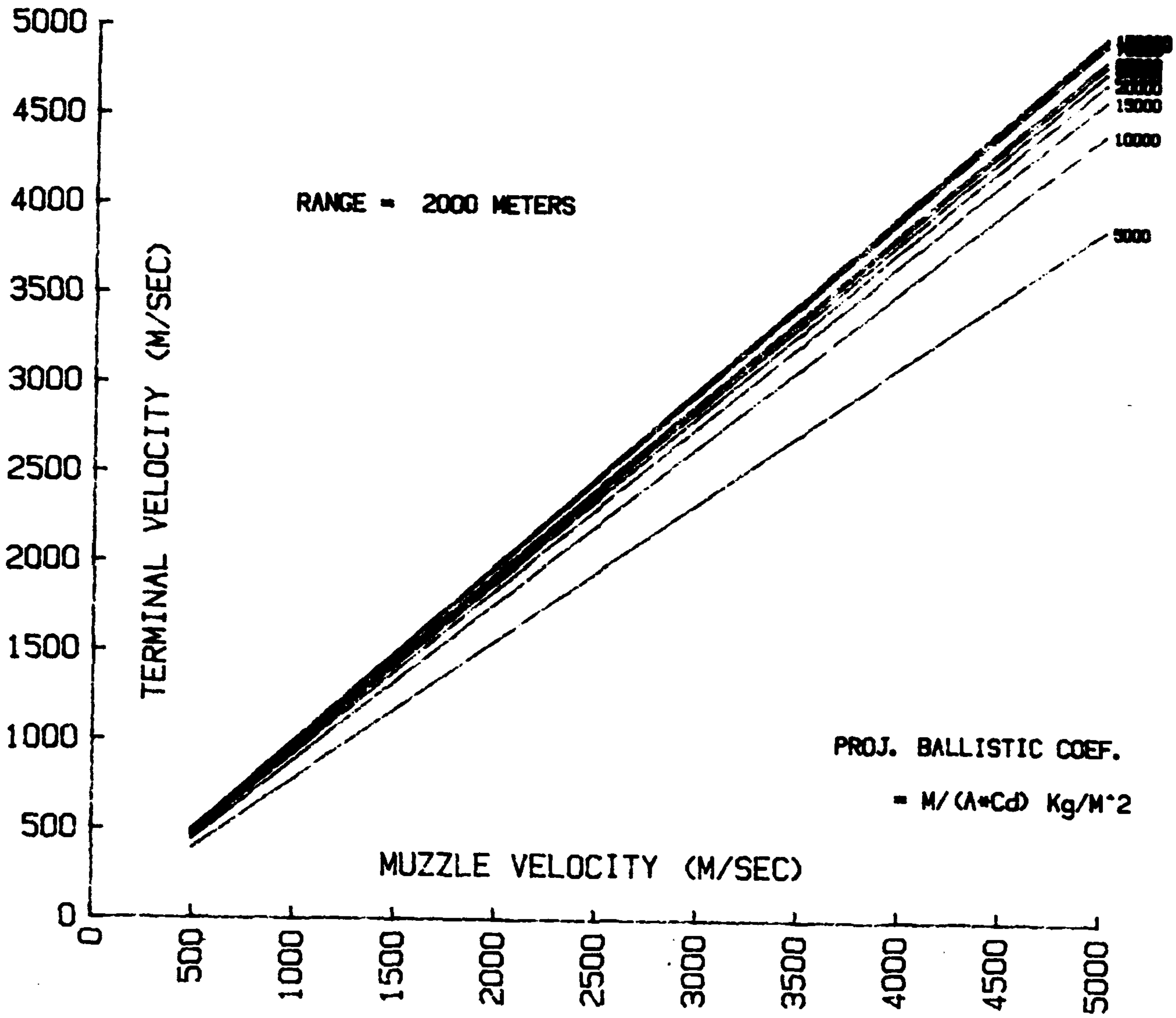


Figure 5.2(c)
Terminal Velocity vs Muzzle Velocity and Ballistic Coefficient

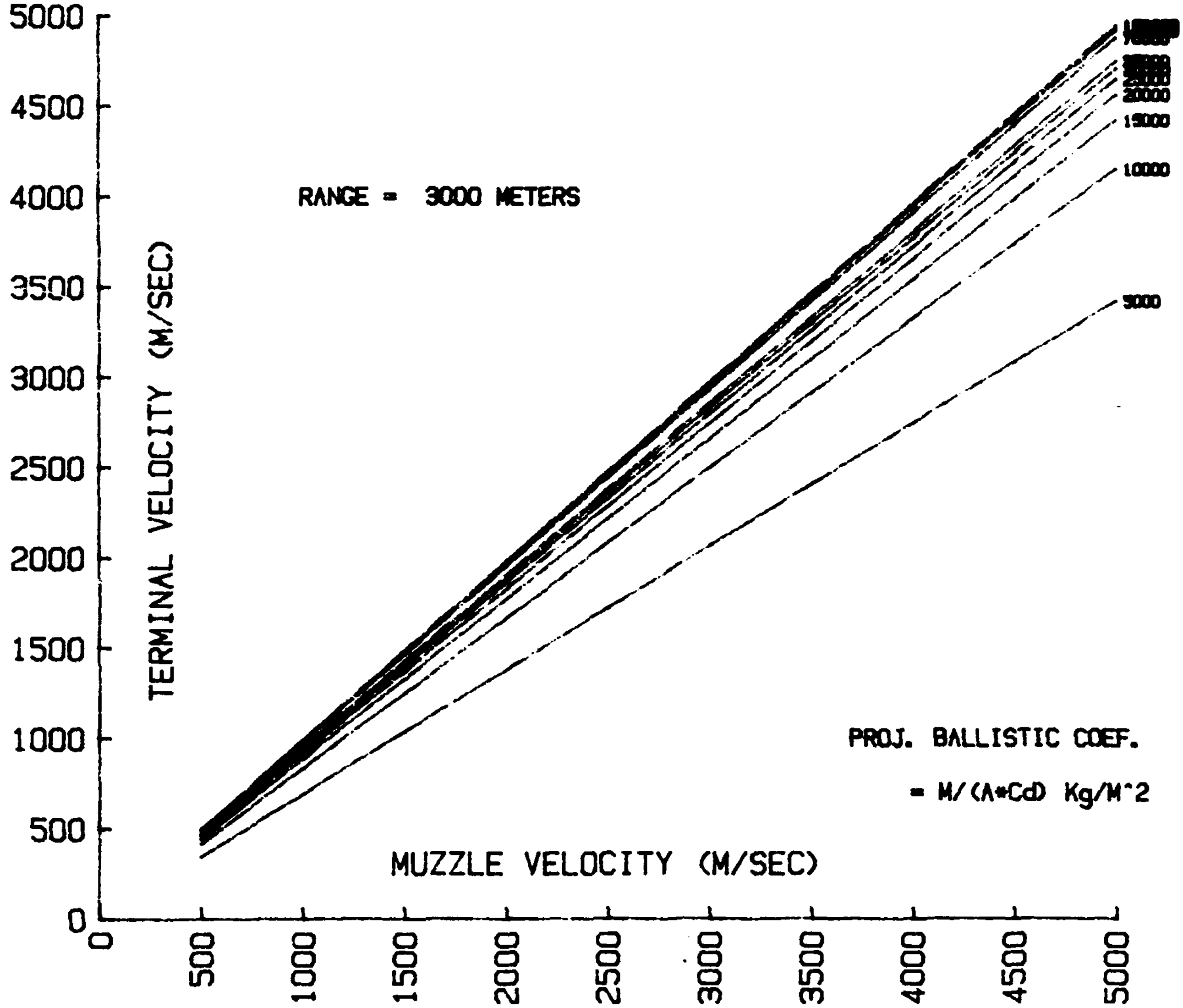


Figure 5.2(d)
Terminal Velocity vs Muzzle Velocity and Ballistic Coefficient

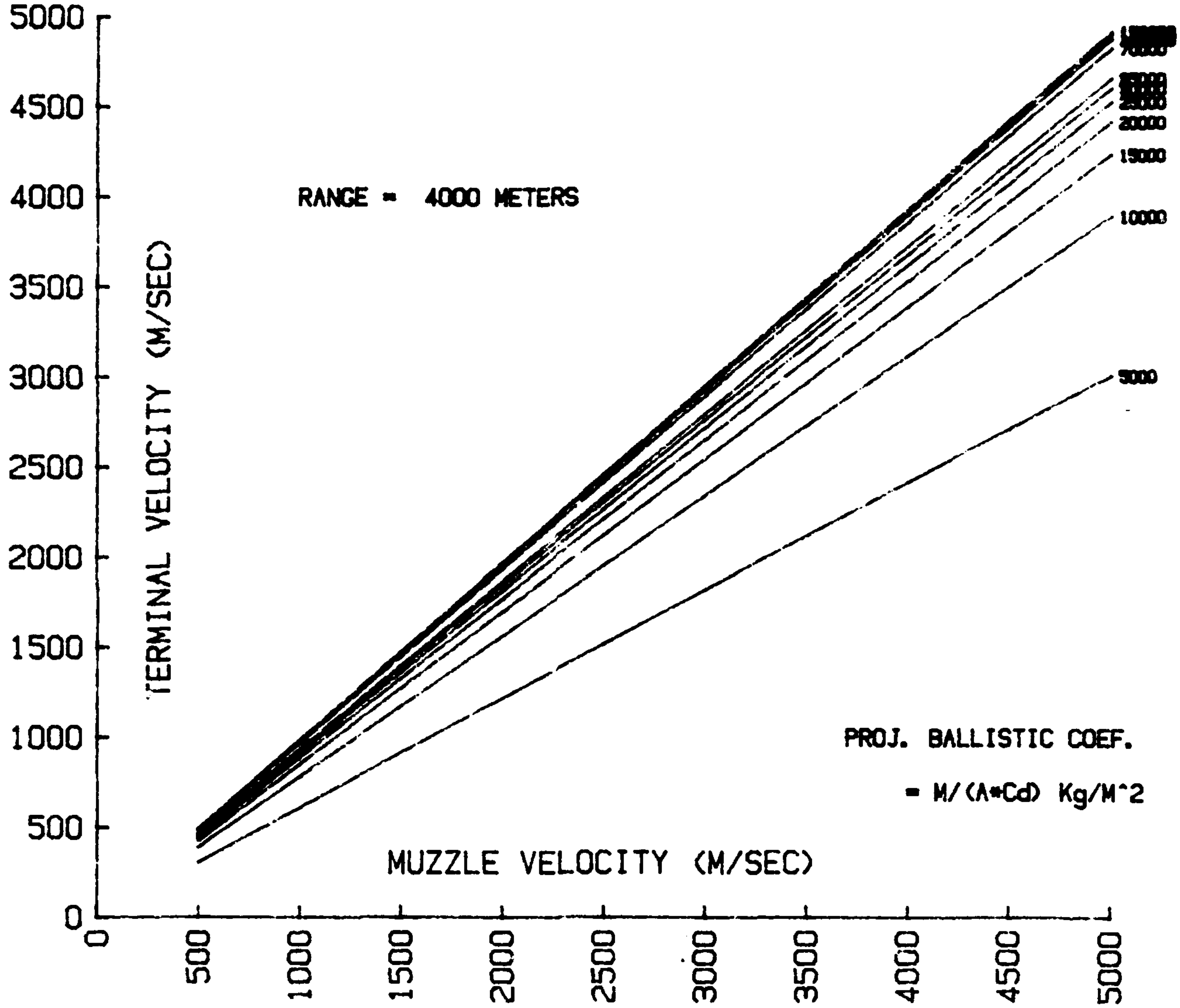


Figure 5.2(e)
Terminal Velocity vs Muzzle Velocity and Ballistic Coefficient

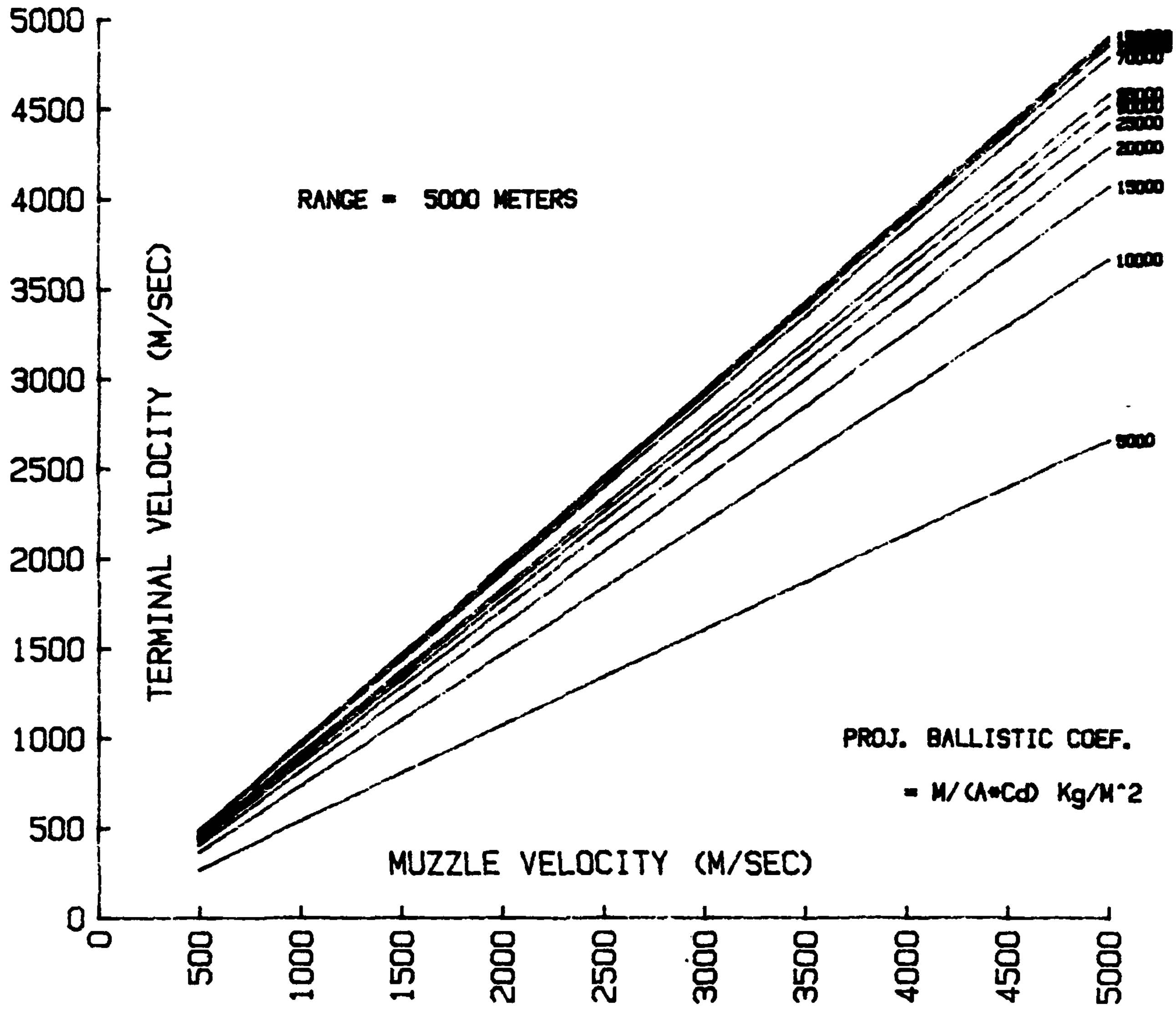


Figure 5.2(f)

Terminal Velocity vs Muzzle Velocity and Ballistic Coefficient

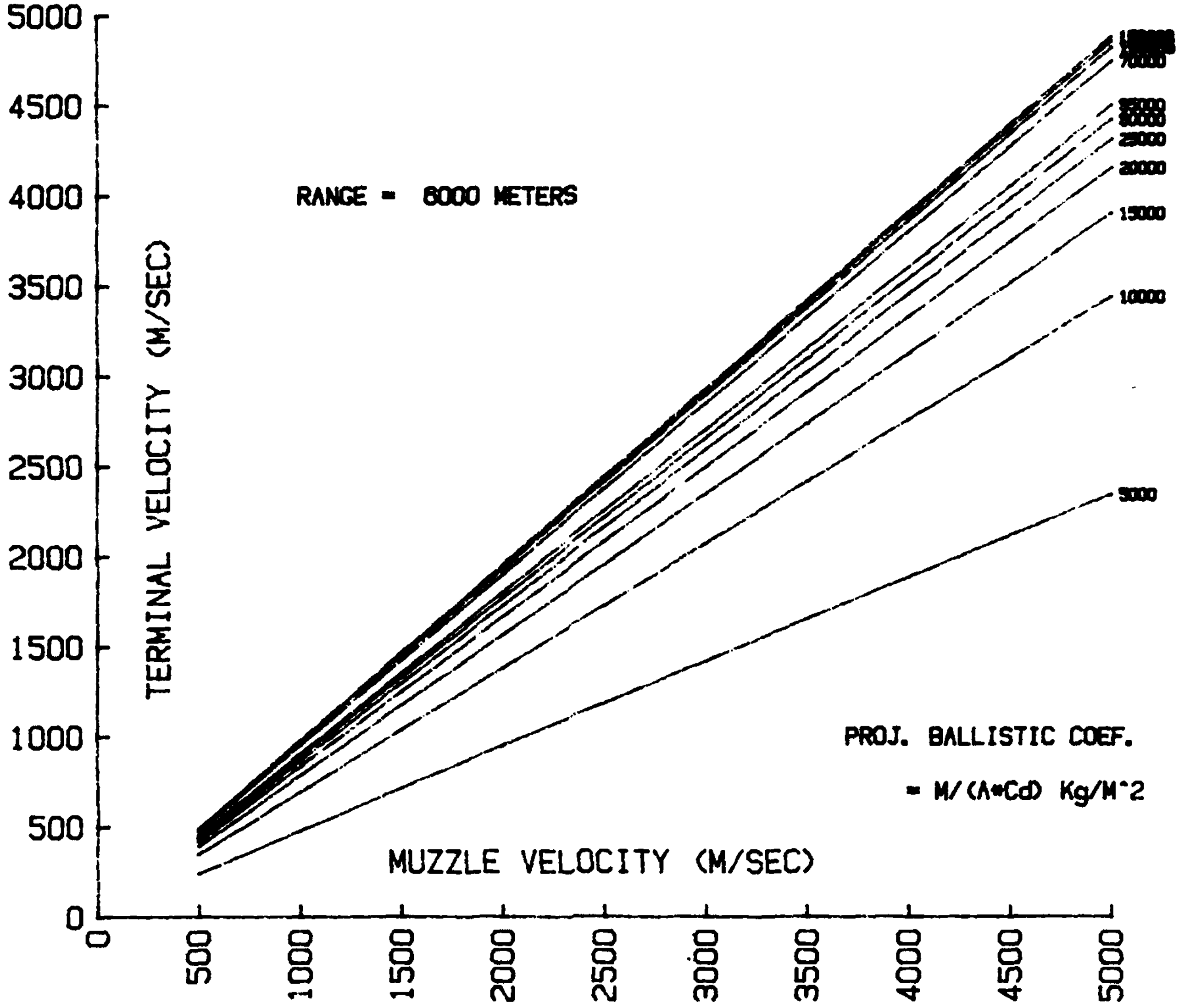


Figure 5.2(g)
Terminal Velocity vs Muzzle Velocity and Ballistic Coefficient

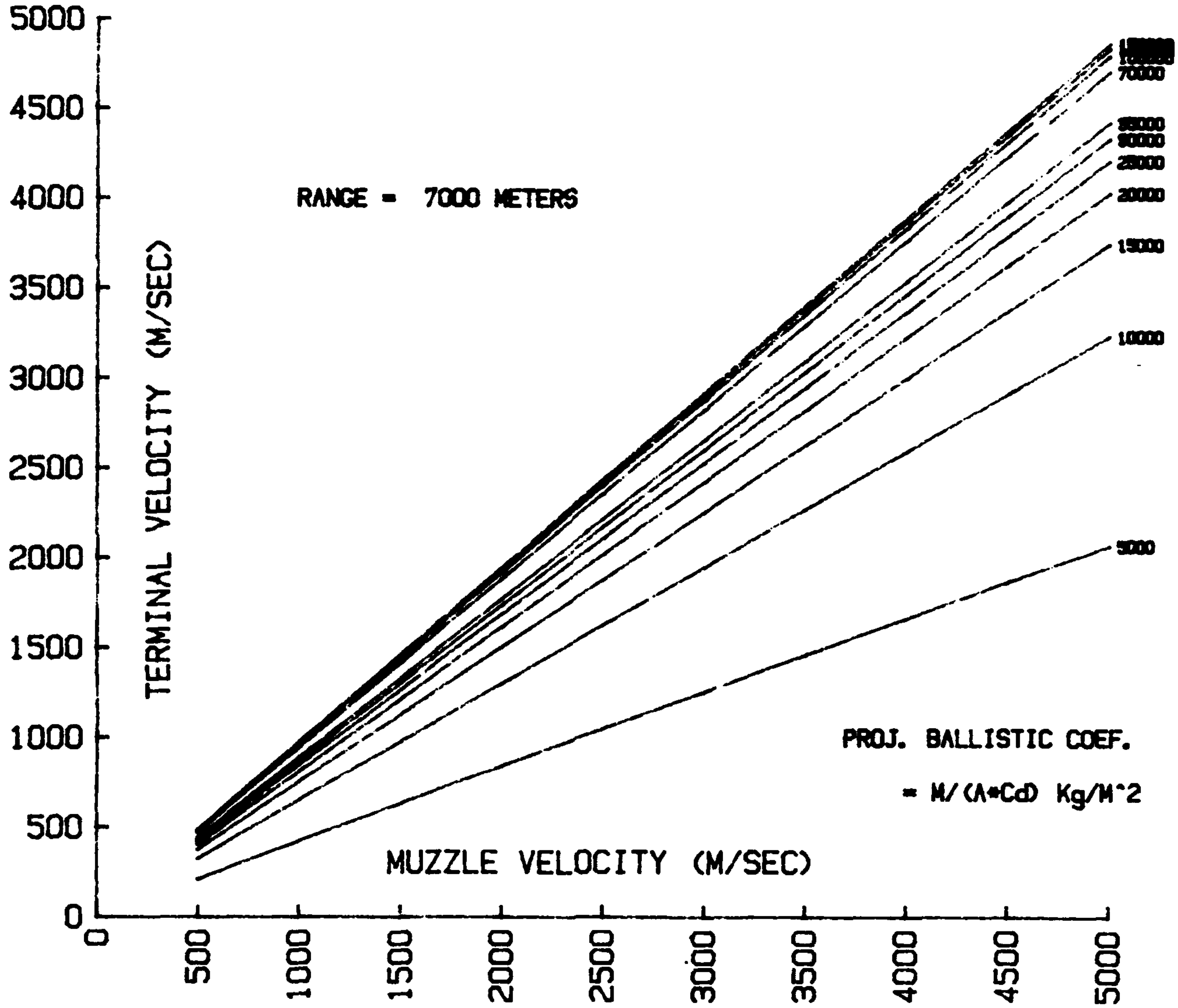


Figure 5.2(h)
Terminal Velocity vs Muzzle Velocity and Ballistic Coefficient

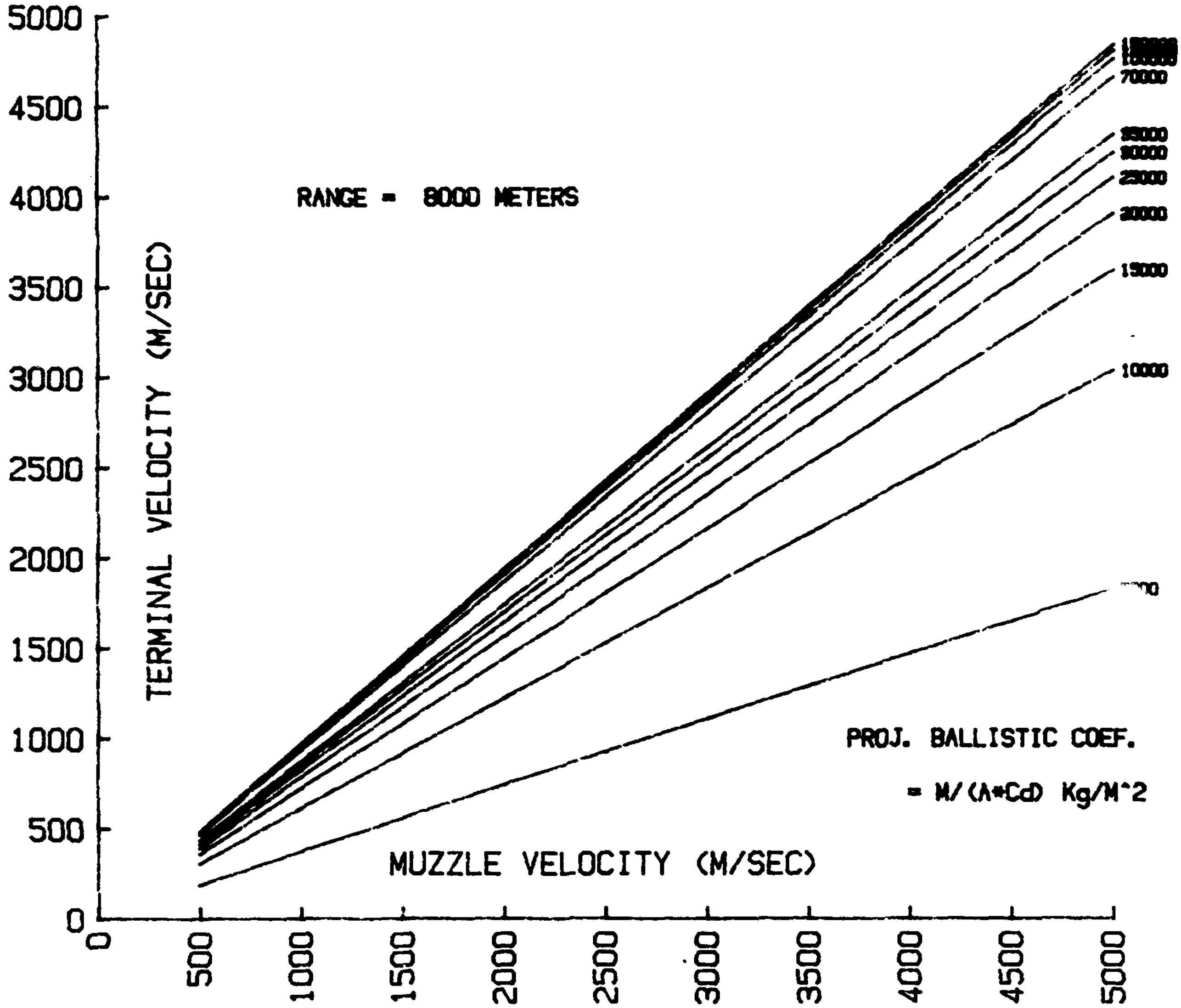


Figure 5.2(l)
Terminal Velocity vs Muzzle Velocity and Ballistic Coefficient

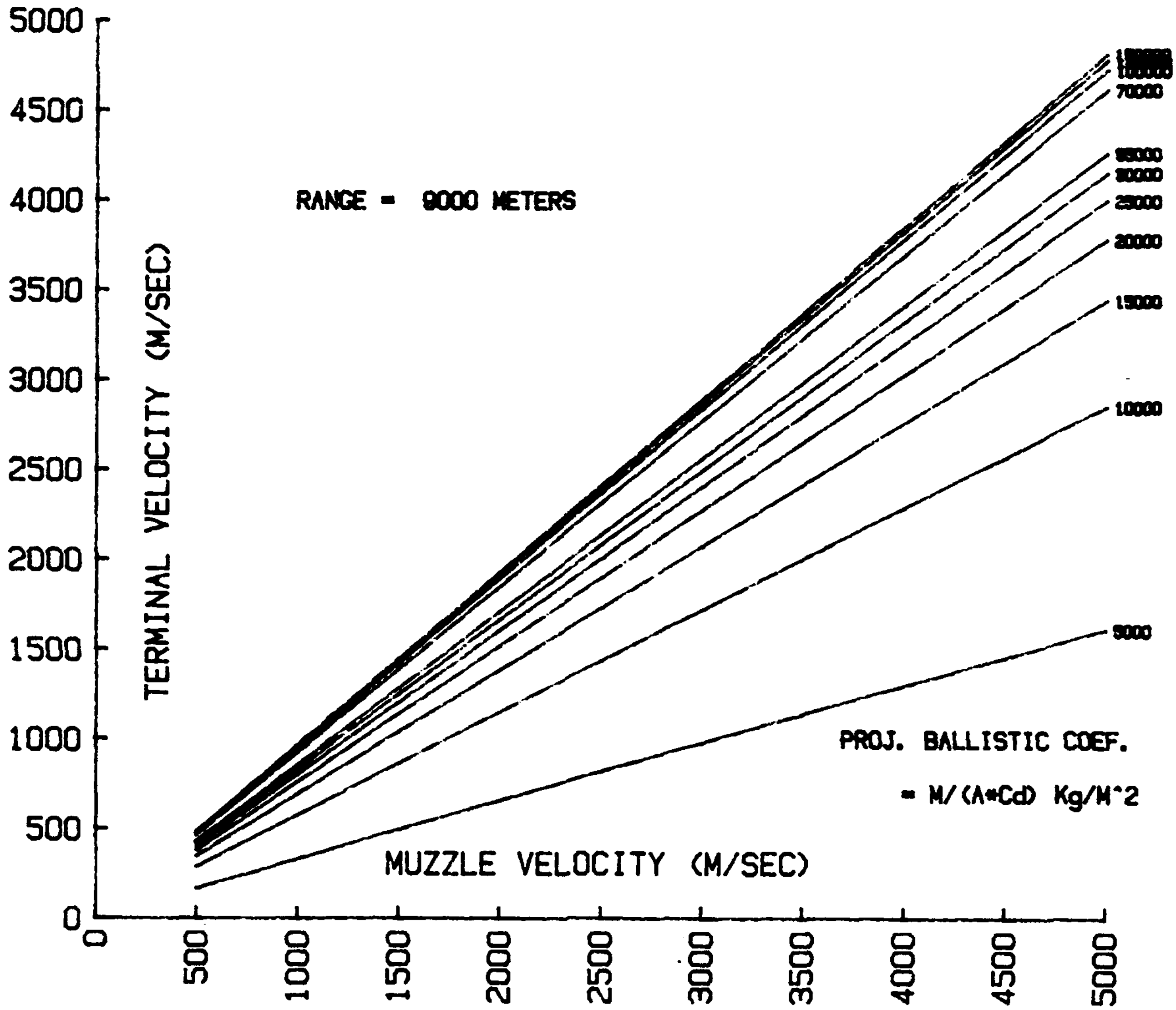
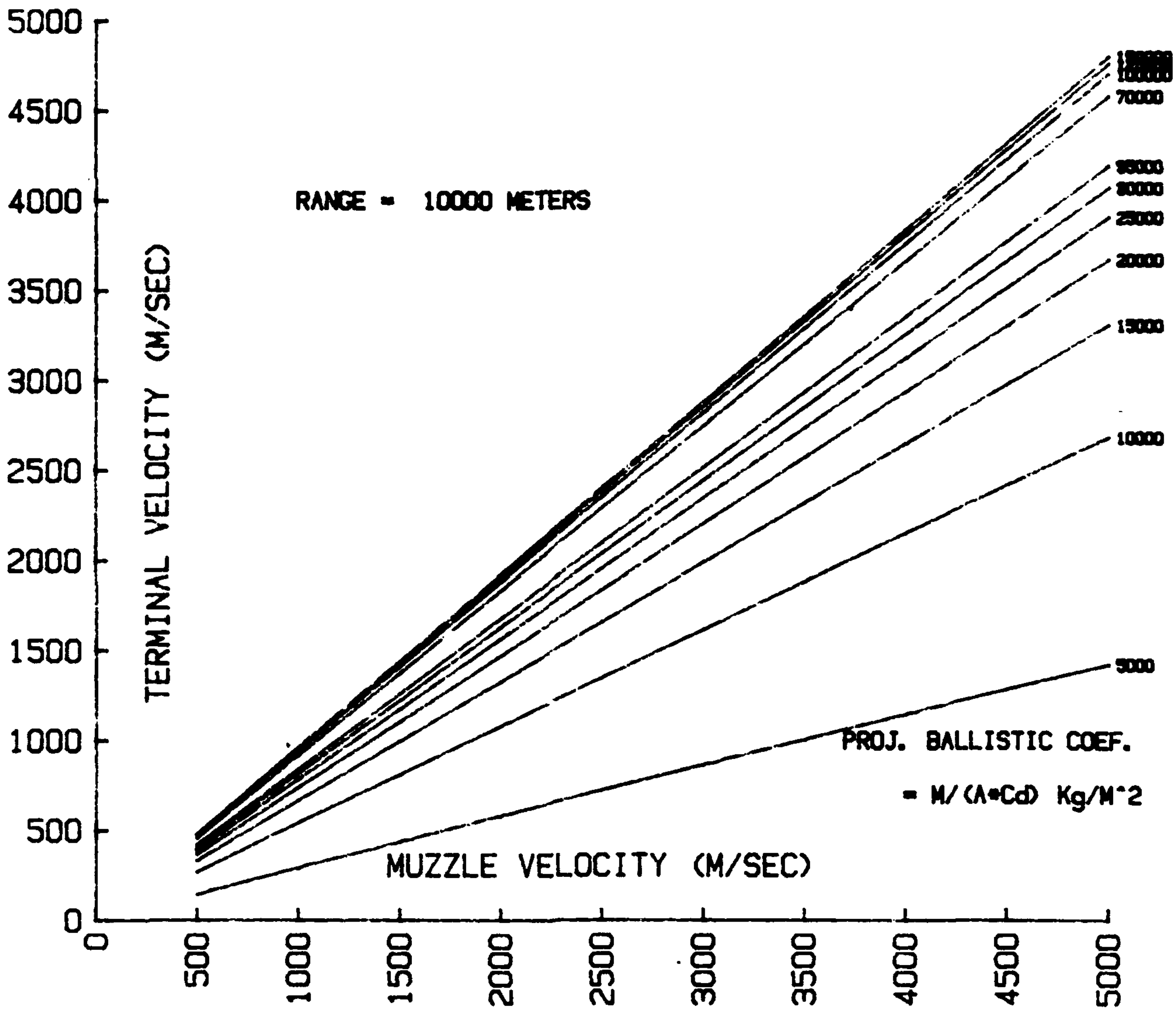


Figure 5.2(j)
Terminal Velocity vs Muzzle Velocity and Ballistic Coefficient



6. SUMMARY AND CONCLUSIONS ON PARAMETRIC TRADEOFFS

These first order approximations on the parametric tradeoffs involved in designing and evaluating conventional cannon and rocket delivery systems shows how complicated any cost and operational benefit analysis will be when assessing the utility of any electromagnetic based propulsion alternative. Unfortunately, many arguments for electromagnetic guns revolve around the assumption that greater muzzle velocity is better. These parametric relationships show that this is not a strong argument. In addition, there remains considerable growth potential with conventional propulsion systems to rival the perceived requirements and capabilities of electromagnetic concepts. Finally, since no electromagnetic gun has yet to be built to any level of combat suitability, weight and space efficiency comparisons against conventional alternatives cannot yet be performed. In any such analysis, the weight and volume of the electromagnetic power supply must also be factored into the weight and space efficient equations.

APPENDIX

SPECIAL OPERATIONS PROJECTILE POINT DESIGNS

PROJECTILE POINT DESIGNS

Two Special Operations projectile point designs were called out in the design summary. The relevant projectile parameters are as follows:

Flight Mass (kg)	Muzzle Velocity (m/s)	Proj Length (m)	Proj Dia (m)	Sabot Mass (kg)	Sabot Dia (m)	Max Acceleration (m/s/s)
0.4	2500	0.20	0.030	0.1	0.040	1.5 x 10^6
2.0	2200	0.40	0.055	0.5	0.065	4.0 x 10^5

The Special Operations Team at Lockheed Aeronautical Systems Company defined similar requirement, as follows:

-- Medium Gun
  25-40mm, .2-.5 kg projectile mass, 2.5 km/sec muzzle velocity
-- Large Gun
  60-80mm, 1.5-2.5 kg projectile mass, 1.8-2.5km/sec muzzle vel.

One concern which arises immediately when evaluating the design summary parameters is that the projectile mass, length and diameter do not fit the density of current kinetic energy penetrator materials. In order to proceed, the desired mass become the design objective, and a reasonable penetrator L/D was established which met penetration, structural, and aerodynamic requirements, and still fell within the design point envelope.

Based on the projectile parameters defined above, initial EM/ET barrel parameters were projected using software developed by the Barrel Panel. The relevant parameters are as follows:

0.4 Kg Projectile

	Gun Type				
	BCC *	CAP	ET	PAR	SAR
Barrel Dia (mm)	113.4	51.1	57.5	41.6	39.5
Barrel Len (m)	10.3	5.8	6.6	5.4	3.2

2.0 Kg Projectile

	Gun Type				
	BCC	CAP	ET	PAR	SAR
Barrel Dia (mm)	144.6	57.0	58.4	57.0	57.0
Barrel Len (m)	8.3	16.5	20.3	14.7	9.0

* BCC (Brush Commutated Coilgun)
CAP (Plasma Augmented Combustion Gun)
ET (Electrothermal Gun)
PAR (Plasma Armature Railgun with CAP Injector)
SAR (Solid Armature Railgun)

The barrel diameters and lengths for the 0.4 kg projectile appear reasonable for the desired performance. Most main tank guns have about 6 meter barrels, although their diameters are much larger. Nevertheless, given the very high muzzle velocity that the 0.4 kg projectile is required to have, and the fact that 150,000 G's is extremely high (current limits are 80,000 G's), this barrel length is unavoidable.

The barrel length for the 2.0 Kg projectile is much too long. This is no doubt due to the low launch acceleration called out, only 40,000 G's. Raising the acceleration limit to 80,000 G's yield the following results:

2.0 Kg Projectile
(at 80,000 G's)

	Gun Type				
	BCC	CAP	ET	PAR	SAR
Barrel Dia (mm)	145.7	76.8	83.6	66.0	62.7
Barrel Len (m)	7.9	8.4	9.9	9.3	4.7

This becomes more reasonable, but still a very long gun tube. This, however, is not an optimal design package, and the G loading could be increased. This is, perhaps, a feasible projectile package, so we proceed with 80,000 G's design acceleration. One caution, however, is that no mention of safety factors is included in this analysis. Most conventional projectiles require a 25% over-design in structures to account for temperature variations on gun pressures. Hence, muzzle velocity is based on a service pressure acceleration and not a design pressure acceleration. If the EM/ET guns above cannot maintain a very tight and reliable acceleration variance, then service launch accelerations and muzzle velocities will have to be reduced to ensure design safety.

400 Gram Projectile Design

Known and proven materials were selected for the design of these projectiles, in order to cut through all the speculation and present a more feasible projectile design. Given the experimental nature of more advanced materials and exotic designs, this becomes a worthwhile approach in establishing baseline projectiles for these EM/ET special operations weapons. The more efficient double-ramp sabot design was selected; however, no provision is made for projectile obturation or armature integration with the sabot.

A penetrator L/D of 10 was selected because this L/D fits into the projectile envelope prescribed in the design summary, it has a low drag coefficient, and efficient armor penetration depth to penetrator length characteristics. Its drag coefficient is about .141, and fired at 2500 meters/sec from an altitude of 15,000 feet at an elevation of -45 degrees, it should impact with a velocity of approximately 2250 meters/sec. These designs use a depleted uranium penetrator, and at this speed the 0.4 kg projectile should penetrate approximately 200 mm of RHA (8 inches). This should be satisfactory over-kill on any light armored vehicle and materiel attacked from the top. The design geometry is as follows:

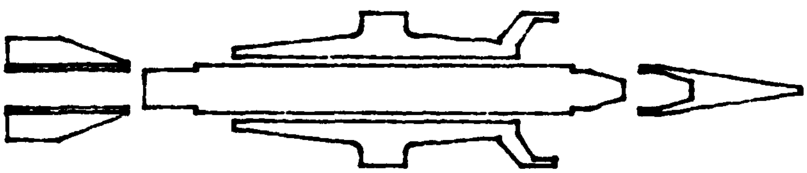
Component	Material	Mass (kg)	L/D	Diameter (mm)
Penetrator	Depleted Uran.	.36	10	14
Nose	Titanium	.010	3	14
Fins	Titanium	.013	n.a.	30
Sabot	Aluminum	.117	n.a.	40
Flight Projectile		.383		
Total Projectile		.500		

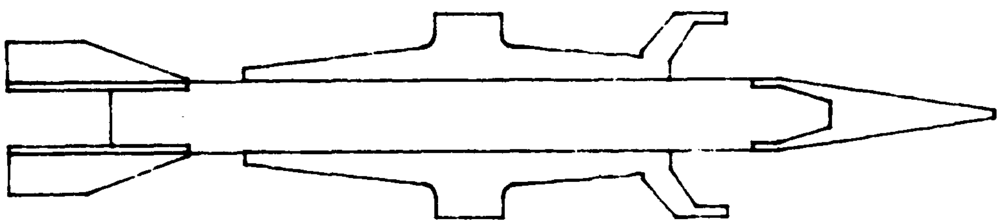
The material properties use in the analysis are:

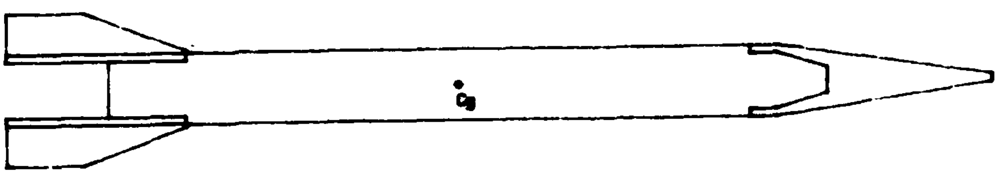
Material	Density (gm/cc)	Yield Strength (MPA/psi)
Depleted Uran.	18.6	690 MPA / 99400 psi
Aluminum	2.8	555 MPA / 80000 psi
Titanium	3.6	750 MPA / 110,000 psi

The aluminum chosen corresponds to a typical very high strength alloy somewhere between AL-7075 and AL-7090. Titanium was chosen for the fins and nose to reduce aerodynamic erosion of these components at high Mach numbers. The yield strength of depleted uranium alloy is a point of debate. It displays a very long, arching stress-strain curve to failure at about 1300 MPA / 190,000 psi, with no clear yield point. However, 690 MPA appears to be where the curvature clearly begins.

The following three figures show the complete projectile in exploded view, for component identification, an unexploded assembly, and the flight projectile. As called out in the design point summary, this projectile can withstand a peak launch acceleration of 150,000 G's.





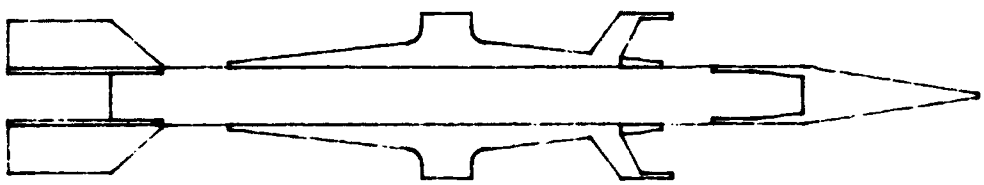


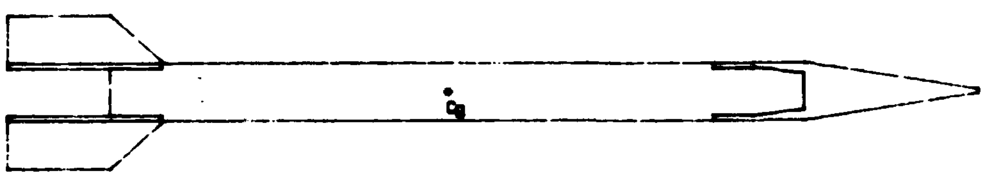
2.0 Kg Projectile Design

This design is based on an a peak acceleration of 80,000 G's, a modification to the point design summary, as stated earlier. It is a scaled up version of the 0.4 kg design. However, the design enveloped allowed an increase in L/D to 12. Given a muzzle velocity of 2200 meters/sec and a drag coefficient of .141, at the same range as for the 0.4 kg design, this penetrator should impact at 2000 meters/sec and penetrate approximately 330 mm of RHA (13 inches). This performance should be able to defeat the top attack armor an any upcoming future battle tank. The design geometry is as follows.

Component	Material	Mass (kg)	L/D	Diameter (mm)
Penetrator	Depleted Uran.	1.843	12	22
Nose	Titanium	.055	3	22
Fins	Titanium	.051	n.a.	60
Sabot	Aluminum	.483	n.a.	65
Flight Projectile		1.949		
Total Projectile		2.432		

The following two figures present the total projectile and flight projectile assemblies.





Alternate Design Concepts

In light of the fact that Special Operations weapons are tasked to attack light armor and materiel, and bunker type fortifications, the rationale of using the above designs, which should be capable of destroying main battle tanks, is questionable. A second issue is assuring the accuracy of the projectile. Given that these are unguided bullets, firing at a maximum slant range of 6500 meters, hitting a relatively small point target such as a vehicle is an exceptional feat. A final issue is the utility of firing kinetic energy munitions against sandbag, log, dirt, and concrete bunkers. These are relatively soft media, providing light resistance to penetration, and hence comparatively little lethal spall. It is most likely that these projectiles will simply sink themselves fifty feet into the earth, affecting no one. In an attempt to resolve these discrepancies, a third design point was added.

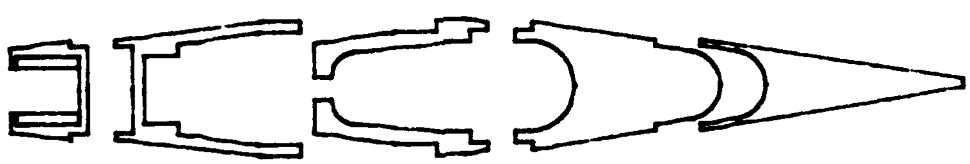
A possible solution for an anti-fortification round is a high explosive mining projectile. This projectile would be build to sufficient strength to survive penetration of the fortification materials, and then detonate inside the bunker. The effective range requirements remain the same. However, impact velocities can be reduced to about 1500 meters/sec. Greater velocities would only provide diminishing returns in soil penetration, while greatly increasing the dynamic loading on the front of the projectile. This projectile should be designed to not deform greatly as it passes through the fortification.

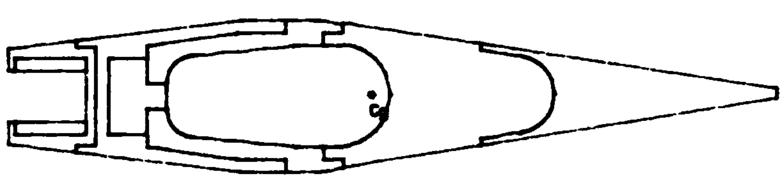
Again, a feasible design was looked for, rather than the optimum solution. A three inch diameter flight projectile was arrived at, which balanced the parameters of mass, length, explosive volume, and aerodynamic drag. Since the drag forces are very high for this diameter projectile, one option called for a spin stabilized round utilizing a base bleed unit. Since base drag of this projectile accounts for half of its total drag, an effective base bleed unit is worthwhile. Base bleed design is very complicated, however, and a rigorous analysis was not undertake. This design uses a scaled version of existing base bleed units.

Spin stabilization of projectiles is perhaps realistic only in the electrothermal guns, since these guns are the more conventional in how the propulsion force is applied to the projectile. Therefore, a fin stabilized option is also presented. Base bleed is possible with a finned projectile. However, such configurations are restricted to wrap-around fins and fixed fins attached to the outside of the boattail. Additionally, the presence of fins has a strong effect on the base bleed performance, as expected. For the purposes of this design, the base bleed is forgone in favor of more conventional boom-type fins. The drag, of course, will increase, however.

The following two figures present an exploded view of the spin stabilized HE-mining projectile components, and an assembly view of the flight projectile. The breakout of the components is as follows:

Component	Mass (lbs)	Material	Diameter (in)
BB Motor	.2973	Aluminum	1.9 (base)
Propellant	.0765	typical	1.5 (o.d.) 1.0 (i.d.)
Fuze Well	.9421	Aluminum	3.0 (max o.d.)
Base Fuze	.1413	typical	1.5 (o.d.)
Aft Cavity	2.742	Steel	3.0 (max o.d.)
Front Cavity	8.72	Tungsten	2.5 (max o.d.)
Wind Shield	1.216	Steel	2.0 (max o.d.)
Explosive Filler	.6383	TNT	2.0 (max o.d.)
Total Projectile	14.77		3.0 (max o.d.) 15.0 length





TNT is not chosen for any great explosive energy reason, but rather because it can be easily cast into the pear shaped cavity, and TNT has good strength properties, important for ensuring projectile integrity during penetration.

The nose shape is a 3 to 1 cone and with the addition of the 7 degree 1.5 caliber boattail the drag coefficient should be near .144. With the addition of the base bleed, this drag coefficient reduces to .089. The base bleed is providing a 50% reduction in the base drag, which is 35% of the total drag of the projectile. With or without the base bleed, a muzzle velocity of 2000 meters/sec will give a terminal velocity between 1600 and 1400 meters/sec, respectively, at the maximum special operations slant range of 6500 meters. This estimate takes into account that the projectile is fired from a rarefied atmosphere at 15,000 feet.

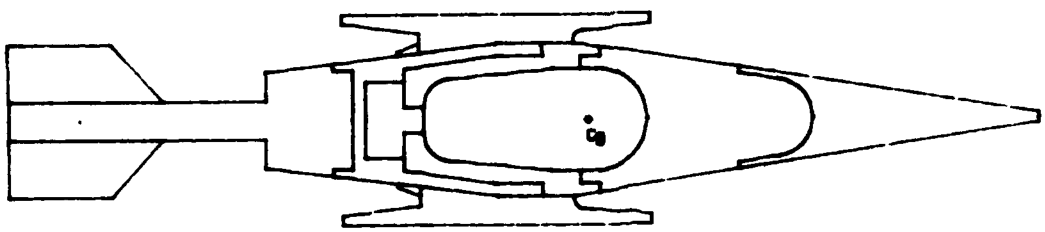
The combination steel-tungsten nose is to provide good penetration capability against combination hard-soft target materials. The conical steel nose will facilitate soft target penetration with out projectile erosion. Should the projectile encounter reinforced concrete or rock, the steel nose will erode and perhaps shatter during impact. However, the truncated tungsten mass will follow through and penetrate the harder material. This concept is a modification of existing armor piercing capped projectiles. The fuze is located in the base of the projectile for obvious reasons.

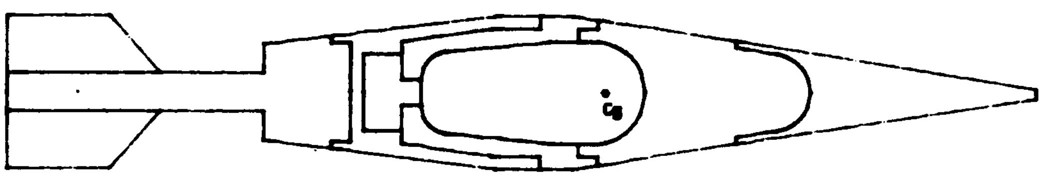
An impact velocity of 1400 to 1600 meters/sec should be adequate for all applications of this projectile. At these velocities, this projectile should penetrate up to 17 feet of earth, or 4 feet of concrete. Sandbags can be considered as earth, and wood logs as less resistant than concrete but more resistant than earth. Different combinations of the various materials will have varying effects on the penetration. A typical bunker will not stand a chance. A hardened pill box with several layers of concrete and earth will fare better. The real trick is the delay timing of the fuze so that it explodes inside the bunker or while penetrating the last inside wall. This projectile will also decimate any light vehicles and perhaps penetrate up to 10 inches of RHA, just like the long rod penetrators. Given the diameter of this projectile, behind armor effects will be catastrophic.

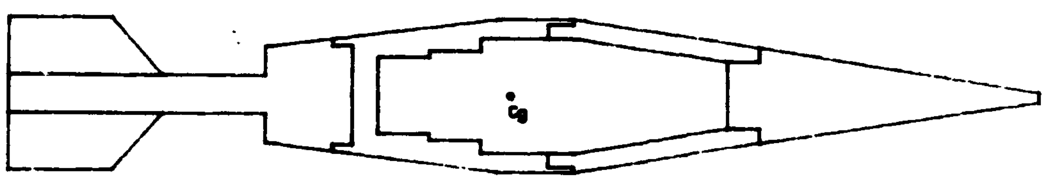
The finned version is shown in the following two figures, with and without a 105 mm sabot. Overall length becomes 20 inches and the addition of the boom and fins brings the flight weight up to 15.5 lbs and the aluminum sabot adds an additional 3 pounds.

To deal with light armored vehicles and materiel, this round can also be modified to carry a cargo of flechettes or heavy metal cubes. The nose is replaced with a proximity fuze, and the steel cavity is hollowed out to provide maximum cargo volume. The concern in this concept is whether the proximity fuze can withstand the launch acceleration.

Depending on how densely the cargo is packed, this round could weigh from 13 to 15 pounds. At 1500 meters/sec, heavy metal cubes could be expected to penetrate their length at distances up to 35 meters from the point at which the cargo round opens up. These cubes can be sized to meet the target's armor and the dispersion of the round. More cubes will give a greater coverage, but less penetration. The same applied to the flechettes. The following figures presents the cargo round concept.







Barrel design estimates given the 2000 meter/sec launch requirement yield the following results:

Projectile Mass = 7.0 Kg (15.5 lbs)
Projectile Dia = 76.2 mm (3 in)
Projectile Len = .80 m (20 in)
Max Accel. = 80,000 G's

	Gun Type				
	BCC	CAP	ET	PAR	SAR
Barrel Dia (mm)	177.7	111.7	119.4	111.7	88.7
Barrel Len (m)	9.3	10.9	13.1	10.9	6.8

These barrels are a little too long., except for the Solid Armature Railgun. However, this design is not optimal. It has only been presented as a possible special operations solution. Two general concern have also been expressed by the special operations experts. One is the muzzle blast conditions caused by current 105mm cannons used in the AC-130. Excessive muzzle blast has forced the shortening of the cannon and, hence, the muzzle velocity of the round. The second concern is cannon recoil on the structures of the airframe. Shortening the barrel has helped alleviate this as well, to the decrement of muzzle velocity. These concerns, however, are not expected to disappear with the use of EM/ET guns. There is the real possibility of plasma blast phenomena, especially with electrothermal guns, and the recoil impulse of these guns will only increase as the muzzle energy is increased. Special Operations applications will still require special design consideration in EM/ET guns.